Effects of Sedimentation on Incubating Coho Salmon,

(*Oncorhynchus kisutch*) in Prairie Creek, California

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EFFECTS OF SEDIMENTATION ON INCUBATING COHO SALMON,

(ONCORHYNCHUS KISUTCH) IN PRAIRIE CREEK, CALIFORNIA

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ABSTRACT

In this study, processes within the actual physical environment surrounding incubating coho salmon (Oncorhynchus kisutch). Embryos were monitored and measurements of environmental factors related to survival were taken. Artificial redds with eyed coho salmon eggs were constructed on treatment and control reaches of Prairie and Lost Man Creeks, California and monitored for incubation survival (hatching and emergence stages), percent fines infiltrating the gravel, and water inflow and dissolved oxygen rates in the winters of 1990 and 1991. Natural redds were also trapped and monitored then compared to artificial redd experiments.

Results indirectly related decreased survival to decreased gravel permeability and predatory oligochaete worm (Haplotaxia ichthyophagous) infestation. Results were consistent the literature; survival varies linearly and inversely with fine sediment in stream gravel and that 'fish effects' can be significant. Other variables ineffectively controlled (site geometric mean particle size, stream gradient and flow) confounded relationships between survival and physical variables measured.

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TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGEMENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	ix
INTRODUCTION	1
Background	1
Objectives	6
Study Area	7
MATERIALS AND METHODS 1991	9
Survival During Incubation	14
Physical Variables Measured	19
Data Analysis	25
MATERIALS AND METHODS 1992	28
Survival During Incubation	30
Physical Variables Measured	32
Data Analysis	33
RESULTS 1991	36
Survival During Incubation	36
Physical Measurements	46
Relationships Between Variables	62

TABLE OF CONTENTS (cont.)

Page

RESULTS 1992 72

Survival During Incubation 72

Physical Measurements 79

Relationships Between Variables 90

DISCUSSION 1991 96

Survival-to-Hatching 96

Survival-to-Emergence 102

Natural Emergence Survival 108

DISCUSSION 1992 112

Survival-to-Hatching 112

Natural Emergence Survival 113

CONCLUSIONS 118

LITERATURE CITED 123

APPENDICES 128

LIST OF TABLES

Table Page

1 Mean Percent Egg Survival and Percent Worm Infestation in Sites with and without Worms in Affected (below Brown Creek, n = 10) and Control (above Brown Creek, n = 10) Reaches of Prairie Creek, 1991. Standard Error is in Parenthesis.. 39

2 Comparison of Mean Percent Fines in Hatching Baskets of Artificial Redds on the Affected and Control Reaches of Prairie Creek, 1991......... 47

3 Comparison of Mean Percent Fines in Emergence Baskets of Artificial Redds on the Affected and Control Reaches of Prairie Creek, 1991............. 51

4 Distribution of Fine Sediment < 1.00 mm by Weight within Freeze Cores Sampled from Affected (n = 6) and Control (n = 6) Reach Emergent Baskets in Artificial Redds, Prairie Creek, 1991........... 53

5 Percentage of Fines < 0.50 mm Composed of Organic Matter, and Percentage of Gravel Sample Composed of Inorganic Fine Sediment < 0.50 mm in Artificial Redds of Affected (n = 10) and Control Reaches (n = 9) of Prairie Creek, 1991. Reach Data are also Pooled (with and without worms).................. 56

6 Comparison of Percent Fine Sediment Found in Natural Redds on the Affected (n = 6) and Control (n = 3) Reaches of Prairie and Lost Man (n = 3) Creeks, 1991....................................... 57

7 Comparison of Mean Inflow Rates in Hatching and Emergence Baskets (n = 10) of Affected and Control Reaches of Prairie Creek, 1991, using Repeated Measures ANOVA. Mean Change in Inflow Rate (cm^3/sec) was Compared Using the T-test....... 61

8 Comparison of Affected and Control Reach Mean DO (ppm) Initially and Post-Incubation in Artificial Redds (n = 10) and Adjacent Surface Water of Prairie Creek, 1991................................ 64

LIST OF TABLES (cont.)

Table		Page
9	Comparison of Initial and Final Mean Dissolved Oxygen Concentrations (ppm) in Artificial Redds (n = 10)and Adjacent Surface Water in Affected and Control Reaches of Prairie Creek, 1991.........	65
10	Correlation Coefficients (r) and Significance for Variables Sampled in Hatching Baskets in Artificial Redds in Prairie Creek, 1991......................	66
11	Correlation Coefficients (r) and Significance Levels (*) for Single Regressions between Percent Fines and Other Variables Measured in Emergence Baskets of Artificial Redds in Prairie Creek, 1991..	69
12	Analysis of Co-variance Tables for Variables Measured in 1991.................................	77
13	Comparison of Mean Percent Fines in Hatching Baskets (n = 20) of Artificial Redds on the Affected and Control Reaches of Prairie and Lost Man Creeks, 1992.................................	81
14	Comparison of Mean Inflow Rates (cm^3/sec) in Artificial Redds (n = 10) in the Affected and Control Reaches using Repeated Measures ANOVA, 1992..	84
15	Affected and Control Reach Mean Dissolved Oxygen Concentrations (ppm), Initially and Post-Incubation in Artificial Redds (n=10) and Adjacent Surface Water, 1992......................................	88
16	Initial and Final Mean Dissolved Oxygen Concentrations (ppm) in Affected and Control Reach Artificial Redds, 1992......................	89
17	Correlation Coefficients (r) and Significance Levels (*) for Single Regressions between Percent Fines and Other Variables Measured in Artificial Redds, 1992......................................	91
18	Analysis of Variance Tables for Stepwise-Backwards Regression Model................	93

LIST OF FIGURES

Figure Page

1 Location Map and 1991 Study Sites, Prairie Creek, CA.............. 3

2 Cross-section and Planimetric View of Artificial Redd.. 13

3 Diagram of Emergent Fry Trap, after Field-Dodgson (1983) and Porter (1973)........................... 17

4 Diagram of Freeze Core and Gravel Substrate Stratified by Depth............................... 21

5 Location Map and 1992 Study Sites, Prairie Creek... 29

6 Survival to Hatch and Emergence within Artificial Redds (bb# = below Brown Creek, ab# = above Brown Creek) on Prairie Creek, CA 1991............. 38

7 Numbers of Fry Emerging from Natural Redds on Prairie (ft#) and Lost Man (lm#) Creeks, CA 1991... 43

8 Stream Temperatures Measured in Prairie Creek, CA between January 11 and July 22, 1991............... 45

9 Percent Fines (< 1 mm) by Weight and Volume from Hatch Baskets within Artificial Redds (bb# = below Brown Creek, ab# = above Brown Creek) Prairie Creek, CA 1991............................ 48

10 Percent Fines (< 1 mm) by Weight and Volume from Emergent Baskets within Artificial Redds (bb# = below Brown Creek, ab# = above Brown Creek) on Prairie Creek, CA 1991............................ 50

11 Distribution of Fines (< 1 mm) in Freeze Cores within Emergent Baskets, as Percent of Total, (bb# = below Brown Creek, ab# = above Brown Creek) Prairie Creek, CA 1991............................ 54

12 Comparison of Inflow Rates over the Incubation Period from Hatching Baskets within Artificial Redds (bb# = below Brown Creek, ab# = above Brown Creek) on Prairie Creek, 1991..................... 59

LIST OF FIGURES (cont.)

Figure		Page
13	Comparison of Inflow Rates over the Incubation Period from Emergence Baskets within Artificial Redds (bb# = below Brown Creek, ab# = above Brown Creek) on Prairie Creek, CA 1991............	60
14	Inflow Rate Change during Incubation of Hatching and Emergence Baskets within Artificial Redds (bb# = below Brown Creek, ab# = above Brown Creek) on Prairie Creek, CA 1991.........................	63
15	Stream Temperatures in Prairie and Lost Man Creeks, CA between January 1 and June 29, 1992.............	74
16	Survival to Hatch within Artificial Redds on Prairie (bb# = below Brown Creek, ab# = above Brown Creek)and Lost Man (lm#) Creeks, CA 1992.....	76
17	Numbers of Fry Emerging from Natural Redds on Prairie (ft#) and Lost Man (lm#) Creeks, CA 1992...	80
18	Percent Fines (< 1 mm) by Weight and Volume within Artificial Redds, Prairie (bb# = below Brown Creek, ab# = above Brown Creek) and Lost Man (lm#) Creeks, CA 1992...................................	82
19	Comparison of Inflow Rates over the Incubation Period of Artificial Redds, Prairie (bb# = below Brown Creek, ab# = above Brown Creek) and Lost Man (lm#) Creeks, CA 1992.........................	85
20	Inflow Rate Change during Incubation of Artificial Redds, Prairie (bb# = below Brown Creek, ab# = above Brown Creek) and Lost Man (lm#) Creeks, CA 1992..	87

INTRODUCTION

Infiltration of large amounts of fine sediments into salmonid redds can reduce reproductive success (Everest et al. 1987). Fine sediments generally reduce the permeability of gravel (Terhune 1957, McNeil and Ahnell 1964), intragravel water flow (Vaux 1968, Cooper 1965), and thus availability of dissolved oxygen. Low dissolved oxygen can cause direct mortality of salmonid embryos (Alderice et al. 1958) or delay development of alevins (Shumway et al. 1964). Fine sediments can also physically interfere with emergence of salmonid fry by blocking interstitial pore spaces causing entrapment (Everest et al. 1987).

Many studies on the effects of sedimentation and salmonid survival have been criticized for not measuring physical variables within the egg pocket itself (Chapman 1988). In this study, processes occurring within the actual physical environment surrounding incubating coho salmon (*Oncorhynchus kisutch*) embryos were monitored and measurements related to survival were made.

Background

Construction of the U.S. Highway 101 Bypass through the eastern boundary of Prairie Creek Redwoods State Park and portions of Redwood National Park (RNP) began in 1984 and was completed in March of 1993 (Figure 1). The purpose of the project, which encompassed about 500 acres and spanned parts of the Prairie Creek and Klamath River basins, was "to divert motor vehicle traffic around the Park so as to best serve the needs of the travelling public while preserving the natural beauty of the Park" (USDT 1984).

The Final Environmental Impact Statement (FEIS) for the project predicted short-term (4-8 years) and long-term (20 years) sediment yields and resultant fishery losses from the construction (USDT 1984). Fishery losses in the southern reaches of Prairie Creek were predicted to be as high as 100% due to siltation of spawning gravel and loss of rearing habitat. Mitigation related to these impacts was required by the FEIS and performed by the California Department of Transportation (Caltrans). Under a memorandum of agreement with Caltrans, RNP began monitoring impacts to salmonid fishes and aquatic invertebrates, and major changes in stream morphology in 1984. Research and monitoring methods of fisheries impacts were reported in RNP (1989, 1991, 1991a).

In September 1989, Caltrans issued a change order to its contractor to extend work, in conflict with the winter deadline for terminating earthmoving work set by the Northcoast Regional Water Quality Control Board (NCRWQCB). Work was continued into the winter and not all erosion

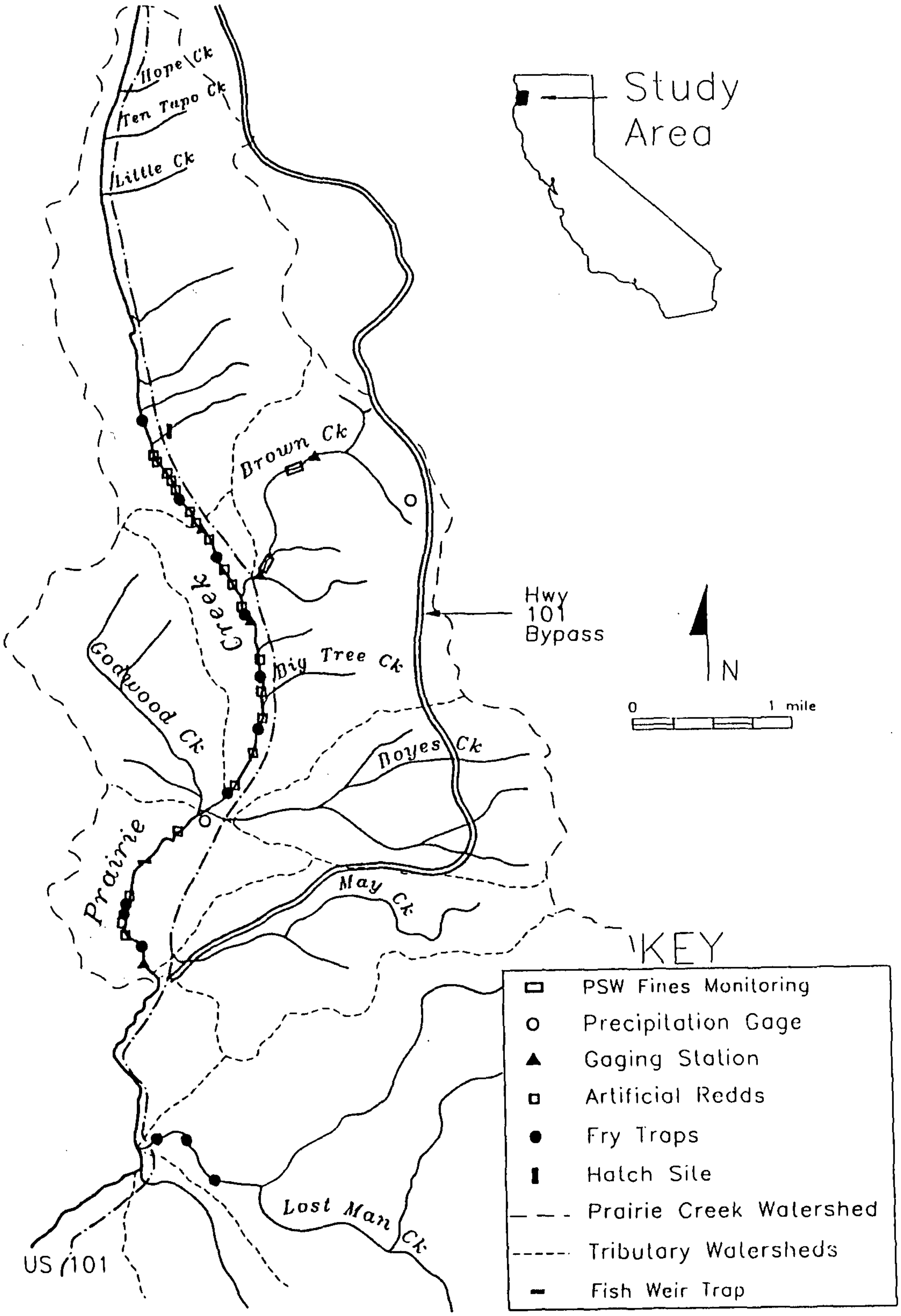

Figure 1. Location Map and 1991 Study Sites, Prairie Creek, CA.

control facilities were installed along a several mile long segment of the project before the first winter storms.

During the first storm between October 20 and 27, 9.4 cm (3.7 inches) of rain fell on the unprotected job site, causing extensive erosion on embankment faces and unprotected ditches (RNP 1989). Numerous mudflows eroding from the project flowed into the small eastern tributaries of Prairie Creek (Ten Tapo, Brown, Big Tree, Boyes and May creeks) (Figure 1).

Under NCRWQCB Cleanup and Abatement Order No. 89-146, a compliance plan was formulated to determine mitigation related to the October storm and to restore fishery losses to Prairie Creek and its tributaries (RNP 1991a). In the plan, Caltrans proposed additional monitoring to determine the extent of the impacts and persistence of materials deposited in the streambeds in October. The monitoring included studies of suspended sediment discharge, surface and subsurface deposition of fines, permeability and dissolved oxygen content of spawning gravel, and steelhead egg survival (RNP 1989). The plan also included mitigation by reintroduction of artificially spawned juvenile salmonids (chinook salmon, _Oncorhynchus tshawytscha_; coho salmon, _Oncorhynchus kisutch_; steelhead trout, _Oncorhynchus mykiss_; and cutthroat trout, _Oncorhynchus clarki_) into Prairie Creek. The Pacific Coast Federation of Fishermen Associations (PCFFA) was contracted to trap adult salmonids in Prairie Creek, and raise the young in streamside hatchery troughs to be released back into the Prairie Creek drainage.

Results of preliminary studies by Redwood National Park (RNP 1989) indicated that steelhead could have successfully spawned and produced sac-fry during the study period, February to April, 1990. Rainfall during 1990 was 67% of normal and flows during the study period were insufficient for mobilizing and re-depositing sediment. More severe storms occurred prior to February when coho and chinook salmon were spawning. Fine sediment accumulations in redds were predicted to be much greater and impacts more adverse.

Results of the 1989-90 winter monitoring (RNP 1989) indicated that much of the fine sediment was still stored subsurface in the creek system. The persistence of the fine sediment is weather dependent and was expected to move episodically as a function of streamflow magnitudes. The sediment and its impacts were predicted to increase in Prairie Creek as the tributaries flushed themselves over time. Success of salmon runs would not be known for 3 to 4 years, and if the survival of salmon eggs was low for several years due to the introduced sediment, the numbers of returning adults might not be enough to sustain a viable population.

To predict the reproductive success of future salmon runs on Prairie Creek, a rigorous study was needed to estimate egg to fry survival rates under normal or higher winter flow conditions. Additionally, the early studies only included that portion of a steelhead's life cycle from the eyed stage to hatching. A study encompassing survival of eggs from fertilization to emergence was needed to assess the full impacts of sedimentation.

Objectives

The overall objective was to determine how sediment inputs from the Bypass Project affected coho salmon embryo survival rates in Prairie Creek. Specific objectives were to:

A. Measure survival of coho salmon from fertilized egg to hatching stage in artificial redds on impacted and unimpacted reaches of Prairie Creek;

B. Measure survival of coho salmon from fertilized egg to emergence stage in artificial redds on impacted and unimpacted reaches of Prairie Creek;

C. Quantify relationships of physical variables in artificial redds (percent fine sediment, intragravel water permeability and dissolved oxygen concentration) with survival of coho salmon embryos;

D. Document timing of emergence and survival from "natural" redds and compare results to "artificial" redds on impacted and unimpacted reaches of Prairie Creek.

Study Area

The Prairie Creek watershed lies within the Coast Redwood Belt near the town of Orick in Northern California (Figure 1). Prairie Creek is a tributary of Redwood Creek. The stream is 22.53 kilometers (14 miles) long, drains an area of 77.7 km^2 (30 mi^2) and flows along U.S. Highway 101 through portions of private agricultural land, Prairie Creek Redwoods State Park (PCRSP) and Redwood National Park. Both parks contain old growth forests characterized by coast redwoods (*Seqouia sempervirens*) and Douglas fir (*Pseudotsuga menziesii*) as the dominant overstory which have experienced frequent disturbance through fire, logging, road building and agricultural development since modern man's arrival in the area.

Four salmonid species reproduce in Prairie Creek and its tributaries: chinook salmon (also called king salmon), coho salmon (also called silver salmon), steelhead trout, and coastal cutthroat trout. These anadromous species generally enter freshwater to spawn from November to March, but run-timing highly depends on rainfall. Chinook salmon typically spawn between November and early January. Coho salmon arrive between November and early February. Steelhead trout enter the system the latest, between February and April. The chinook salmon primarily spawn in the mainstem, whereas coho salmon and steelhead trout spawn in the tributaries as well.

The study area is that portion of the stream lying within the two parks' boundaries from the confluence of May Creek to 2.4 kilometers (1.5 miles) above Brown Creek, the approximate limit of suitable spawning habitat (Figure 1). The reach on Prairie Creek above the Brown Creek confluence, and a portion of Lost Man Creek were chosen as controls because they were the least affected by fines from the Bypass.

MATERIALS AND METHODS

1991

Methodologies are discussed separately by study year for readability because study methods changed. In 1991, twenty sampling locations were randomly selected within strata of the two stream reaches of Prairie Creek; ten above the confluence of Brown Creek and Prairie Creek, and ten below. Sample size was estimated from sample variances measured in the 1990 RNP study. In the RNP study, data were collected on the movement and storage of fines in Prairie Creek between the confluences of the impacted tributaries. Each tributary experienced increasing cumulative effects of sediment introduction extending from Brown Creek to May Creek. Therefore my sample locations below Brown Creek were stratified between each of the three impacted tributaries (Figure 1). Sample locations above Brown Creek were stratified over three equal distances.

In 1992, sampling locations were again randomly selected within strata of the two stream reaches, however a third stream reach on Lost Man Creek was added as a control. Greater proportions of sample sites were also placed in stream reaches most used by natural spawners. Sites were chosen by randomly selecting locations in each strata on a map and then selecting on the ground the closest 'suitable' riffle crest to that location. 'Suitable' riffle crests were identified using criteria developed from observations by Briggs (1953) on spawning habitat use by coho salmon on Prairie Creek. Briggs observed fish spawning in areas of a mean water depth of 15.7 cm (6.2") and ranging from 102 to 203 cm (4 to 8"), mean water velocity of 0.58 m/sec (1.9 ft/sec, range 1.0 to 2.5) and mean gravel size of 71 mm (2.8") and ranging from 38 to 101 mm (1.5 to 4"). Riffle crests were then selected in stable reaches free of influence by organic debris, during winter base flow periods.

Procedures for estimating egg survival were adapted from Burton et al. (1990) and Redwood National Park (1989). Artificial redds were constructed at each sampling location and consisted of two baskets, one to test survival to hatching and one to test survival to emergence). Coho salmon eggs were obtained by trapping adult upstream migrant spawners on Prairie Creek. The trap was operated by personnel from PCFFA who were under contract with Caltrans and CDFG.

Because only two artificial redds could physically be constructed per day, all redds were constructed prior to placing egg baskets in the stream, which enabled synchronized egg placement and equal incubation time for eggs. Redds were then subjected to similar conditions during the incubation period. Stream flows, rate and delivery of dissolved oxygen, stratigraphy of fines in the gravel layer, temperature and emergence time of alevins, were expected to vary during the incubation period.

Artificial redds were constructed to mimic the characteristics of natural redds (i.e., water depth and velocity, substrate size, and surface contour). Each redd was constructed by digging upstream to form a pit approximately 40 cm deep. Effort was made to sift the gravel with a shovel much like a salmon might while building a redd. Approximately one third of the gravel removed from the pit was sieved with a 4.75 mm sieve and stored on the bank until fertilized eggs were available. A 4.75 mm sieve was used because substrate samples collected from natural redds by RNP (1989) showed that spawners cleaned redds of most fine material less than 4.75 mm.

Two 25.4 cm (10") diameter bottomless buckets were placed into the pit to prevent the sides of the pit from collapsing until eggs and gravel were introduced. The sides of each bucket were slit to orient the cables of an infiltration bag which was positioned in the lower 5 cm of the bucket. The 30 cm diameter infiltration bag was folded accordion-style in the bottom of the pit (40 cm), such that the egg basket sat above (30-35 cm). The cables and floats extended from the collapsed bag through the gravel layers to the surface for later extraction. The infiltration bag was used to capture gravel and facilitate removal of the basket.

Rocks and gravel were back filled around the bucket to hold it in place using the same sieved gravel excavated from the pit. The bucket was then capped and several large rocks placed on top of the lid to prevent flow from eroding the pit. Thus, redds were still free of fines several weeks later when eggs became available. Eggs were deposited into all the redds over a three-day period. Each egg basket apparatus was filled with the stored sieved gravel and 100 eggs, deposited into the bucket, buried, and the bucket removed.

A final pit (representing the pot) was dug just upstream of the pit and the shovel-sieved gravel allowed to tumble downstream so it covered the redd (Figure 2). Briggs (1953) found coho eggs at 22.9 to 27.9 cm (9 to 11 inches) below the gravel layer in Prairie Creek. Thus, the center of each egg basket was located between 23 and 28 cm below the gravel layer in my study. Egg baskets were constructed of 3.2 mm (1/8-inch) polyethylene netting with a hollow perforated aluminum tube (35 cm long) set into the center of the basket which extended up through the gravel layer to the surface (Figure 2). The downstream baskets were 15 cm high and were used to test survival to hatching. The upstream baskets were 30 cm tall, sat flush with the surface layer of gravel and were used to test survival to emergence. Several large cobbles 64 mm to 128 mm were carefully included in the pocket to allow enough pore space for intragravel water

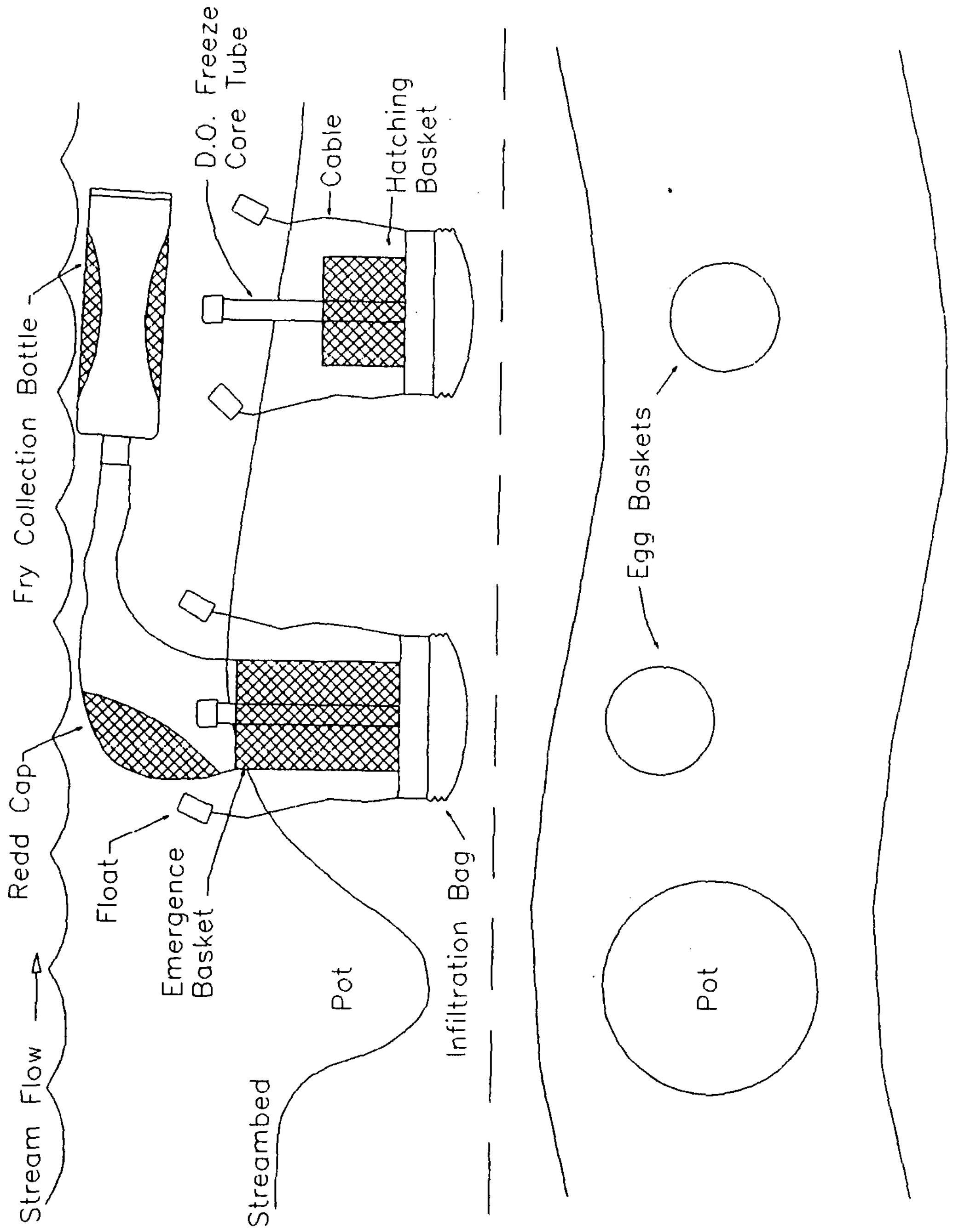

Figure 2. Cross-section and Planimetric View of Artificial Redd.

exchange (Chapman, 1988). Egg baskets in each redd were located about 1 meter from each other. Baskets were placed in Prairie Creek during the same time period that natural spawning occurred.

Salmonid eggs become extremely fragile 24 hours after being fertilized until they reach the eyed stage several weeks later (pers. comm., M. Farrow, 1990, PCFFA, Arcata, CA 95521). Thus, special care was required when counting recently fertilized (green) eggs and when placing them in the egg baskets. Eggs were carefully counted at the hatch trough site using an egg counting board, separated into cheese cloth bundles of 100, and suspended in capped buckets of water during transportation. During transportation water temperature was held within 2° C of stream temperature and the eggs were slowly re-acclimated before depositing into the egg baskets. Specific details intrinsic to each monitoring method are explained below.

Survival During Incubation

Survival to Hatching. One egg basket in each redd was removed at estimated hatching time (between 6 and 11 weeks) and the other removed after all fry were estimated to have emerged (2 to 8 weeks longer). Stream temperatures were monitored during incubation. Timing of removal of egg baskets was calculated using the temperature unit method described by CDFG (1980), whereby one temperature unit equals one degree Fahrenheit above 32°F (0°C) for a 24-hour period. A McNeil sampler was pushed partly into the substrate around the basket prior to winching with a come-along attached to the infiltration bag cables. This procedure: 1) prevented sloughing of the sample out of the infiltration bag; 2) created an eddy of slack water around the basket which prevented bleeding of fines; and 3) minimized disturbance to the emergence basket, which would be removed several weeks later. After the first basket and bag were removed, the resulting pit was refilled with gravel through the McNeil sampler.

Dead eggs, live alevins and emergent fry were enumerated to calculate percent survival in artificial redds. Survival rates for each egg basket were then adjusted according to respective fertilization, viability and handling mortality rates which had been calculated. Visual estimates of numbers of predatory oligochaete worms found in samples were ranked (high, medium, low, none) to determine their relationship to egg survival.

Survival to Emergence. Emergence survival was measured separately from the hatching stage. Emerging fry were caught in a modified redd cap which was fitted over the redd prior to emergence (Figure 2). Designs of redd caps were adapted from Burton et al. (1990) and Porter (1973). The redd caps were checked at least every other day with the onset of emergence. Emergent baskets were removed a few days after cessation of fry emergence. Prior to emergent basket removal, freeze cores were taken using the aluminum tube within each emergence basket to determine the vertical stratigraphy of fines intruding into the cleaned gravel. A plugged piece of copper tubing slid into the permeability pipe acted as a valve to close off perforations in the bottom of the pipe. The column of gravel, fines and water around the permeability pipe were then frozen with pressurized carbon dioxide, allowing a solid vertical gravel core to be removed which extended from the surface to the egg pocket.

The emergent egg basket apparatus was then quickly removed with a process similar to that used with hatching baskets, and dead eggs and fry were counted. The stratigraphy of the freeze core was preserved in a three chambered tray and sieved later in the lab. Predatory worms in emergent baskets were weighed to better quantify their abundance to determine their relationship to egg survival.

<u>Natural Emergence Survival</u>. Emergence success of "naturally" spawning fish was estimated using fry traps, adapted from designs by Field-Dodgson (1983) and Porter (1973) (Figure 3). Spawning surveys were conducted on Prairie and Lost Man Creeks throughout each winter. Redds were identified, dated and marked, and, when present, fish species and length recorded.

Seven traps were placed below the confluence of Brown Creek (two below each affected tributary) and three placed

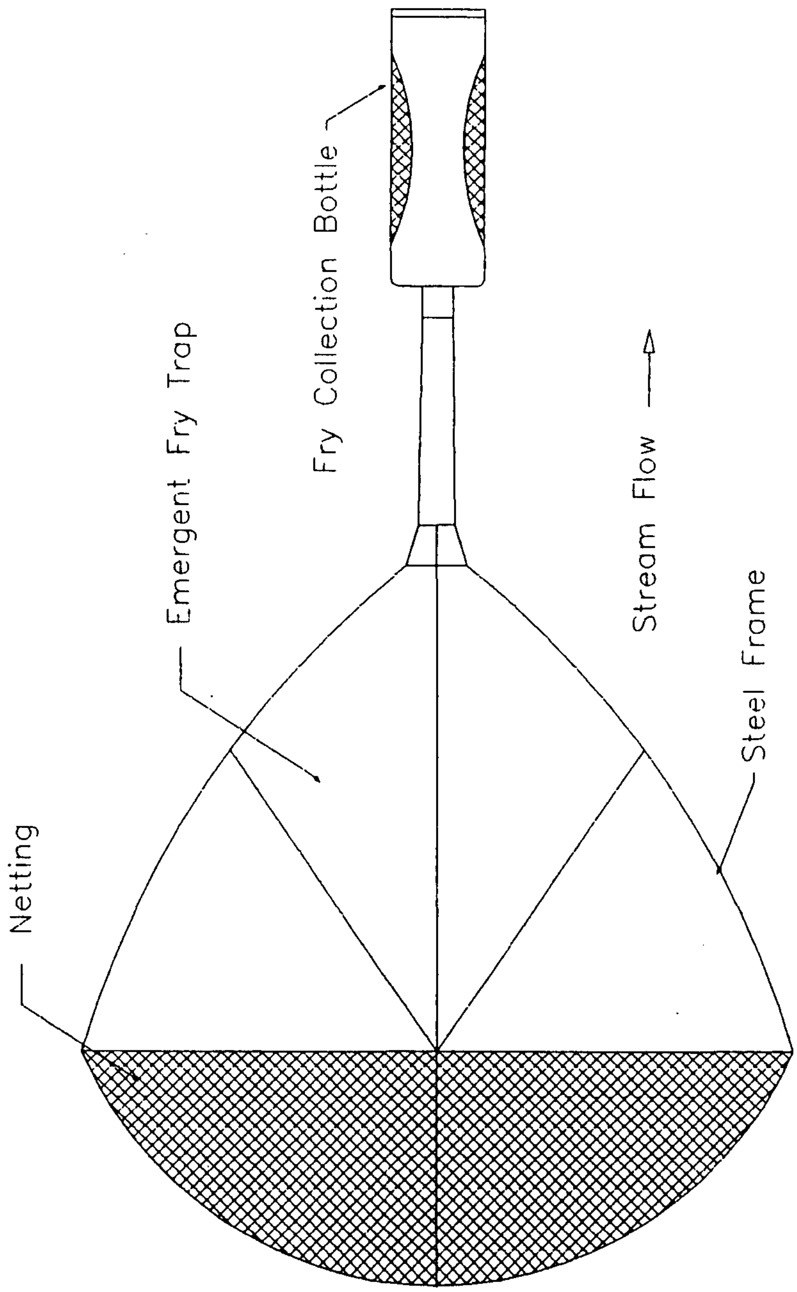

Figure 3. Diagram of Emergent Fry Trap, after Field-Dodgson (1983) and Porter (1973).

in the control reach above the confluence (Figure 1). Three additional fry traps were installed on Lost Man Creek as a separate control stream.

Fry traps were installed on the marked redds several weeks prior to estimated emergence and monitored at least every other day for emerging fry. After all fry had been estimated to have emerged, the traps were removed, and McNeil samples were taken to document percent fines. Two redds were examined for dead eggs, entrapped fry and/or predatory oligochaete worms, however, the procedure proved too inefficient to make valid observations.

Controls. The remaining eggs from each female used in artificial redds were incubated in "hatch boxes" by PCFFA to determine the fertilization rate (percent eyed) and proportion of viable embryos (percent hatched). These eggs were incubated on plastic mesh under continuous upwelling flow from a nearby non-sediment impacted tributary of Prairie Creek using standard hatchery practices (CDFG 1980).

After all eggs were estimated to have eyed by PCFFA hatchery personnel, the percentage of eggs with cellular development was determined through "addling" the eggs in a rubber hose. This procedure isolated developmental mortality from mortality due to environmental variables. This percentage was then used to 'adjust' survival rates for artificial redds. Additional egg baskets were subjected to the same handling procedures as the experimental baskets, to determine mortality due to handling. In 1990, one basket was placed in a small unimpacted tributary of Prairie Creek at the PCFFA hatch trough site (Figure 1). The percentage of eggs that eyed was determined by PCFFA personnel and compared to the percentage of eyed eggs in the hatch box. The difference was attributed to handling mortality.

Physical Variables Measured

Substrate composition, intragravel permeability and dissolved oxygen concentrations were monitored in artificial redds to determine relationships with embryo survival. Peabody-Ryan recording thermographs were installed near RNP's permanent gauging stations (Figure 1) on Prairie Creek. A third unit was installed in Lost Man Creek. Temperature data from Campbell systems operated by RNP personnel and data from the County-operated Prairie Creek Fish Hatchery were also used. Temperature measurements were converted to temperature units (each 1° increase above 32°C equals 1 degree day) to estimate the stage of incubating embryos (CDFG 1980). This enabled monitoring of physical variables and timing of basket removal during critical points of each life stage.

Substrate Composition. All substrate samples from emergence and hatching stages, and natural redds were wet- and dry-sieved to determine size classes (> 256, 128, 64, 45, 32, 22, 16, 11, 8, 5.6, 4.75, 4, 2, and 1 mm) by volume and weight respectively. Sample fractions were oven-dried at

100^{0} C and weighed. Volume measurements were made using water displacement. Suspended material < 0.50 mm was poured into Imhoff cones and the resulting settled volume of fines recorded after 45 minutes. Wet volumes were converted to dry volumes (Platts et al. 1983) to remove the water gained in the sieving process.

Percent fines < 4.75 mm, < 1.00 mm and < 0.50 mm were calculated to obtain the total increase in percent fines infiltrating cleaned gravel over the incubation period. Sieve data were analyzed by calculating the percentage of the sample weight finer than each sieve size used, thus the term 'percent fines' in this report represents 'cumulative percent finer than' for simplicity. The 1.00 mm size fraction was compared to other parameters because this size fraction represented the largest proportion of the fines in the redds and is a similar size used in other studies (Cederholm, 1981 and Tagart, 1976).

Gravel basket data were truncated at 64 mm because: 1) basket weights were small so samples would be skewed by very large particles; 2) cobbles > 64 mm were introduced artificially into the baskets; and 3) data between life stage treatments could be comparable. Freeze core gravel data were stratified by depth (Figure 4).

The organic matter component within sediment samples in egg baskets and infiltration bags was separated to: 1) determine if proportions of organic matter were different

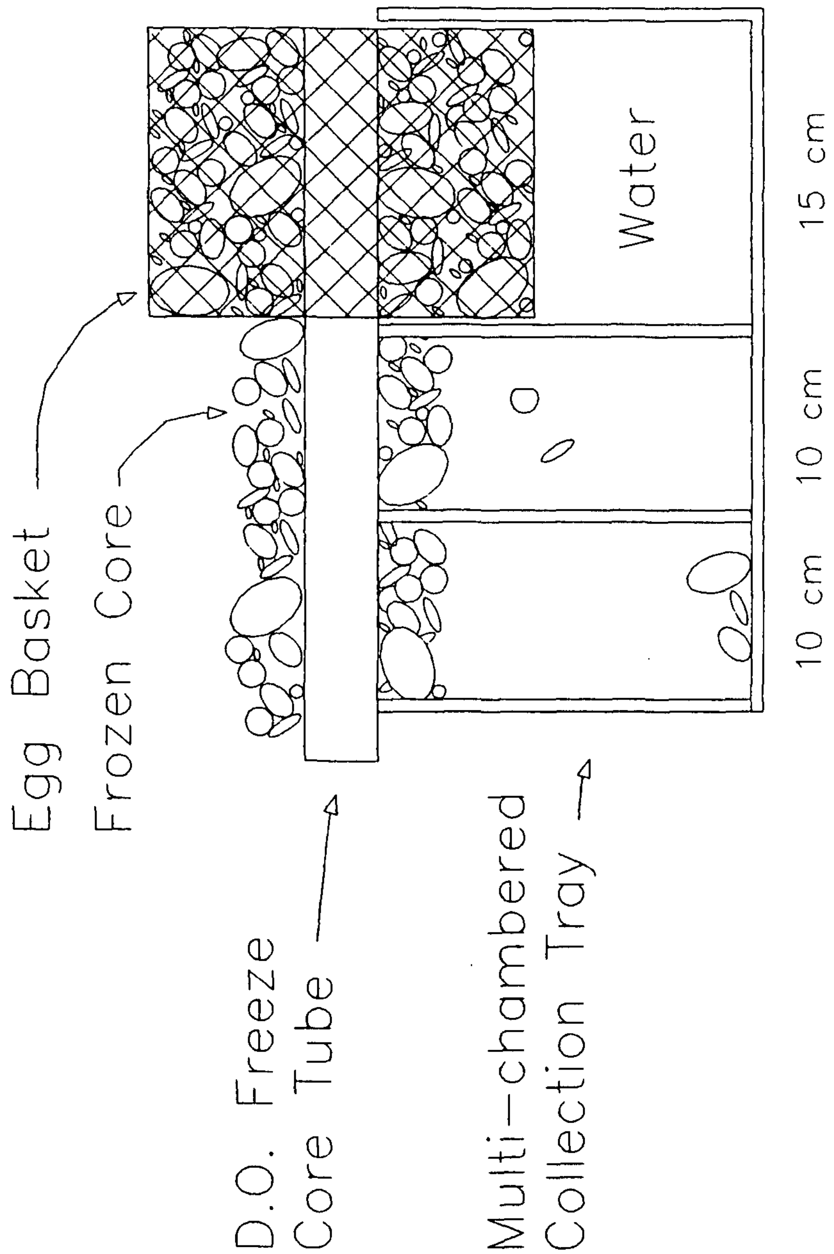

Figure 4. Diagram of Freeze Core and Gravel Substrate
Stratified by Depth.

among treatment reaches; and 2) determine any relationship between percentage of organic matter and quantities of predatory oligochaete worms found in egg baskets. The fine sediment < 0.05 mm from hatching baskets and infiltration bags was analyzed to determine the percentage of organic matter within each sample following the methods of Ball (1980).

Sub-samples of 5 gm were obtained by repeated splits of whole samples and weighed before and after burning for 24 hours in a muffle furnace at 232° C (450° F). Sub-sample percentages were determined from the difference between these weights. Sub-sample percentages were also subtracted from the overall substrate sample weights to determine "true" particle size distribution curves. Percent fines were then statistically analyzed using T-tests to test for differences in the affected and control reaches.

In 1991, McNeil gravel samples from natural redds were taken following the methods of McNeil and Ahnell (1964), so that comparisons to artificial redds and relationships between percent fines and natural survival could be made. Particle size distribution by weight and volume was determined following the methods outlined above. Results were analyzed using the non-parametric Kruskal-Wallis (K-W) test.

<u>Permeability and Dissolved Oxygen</u>. Permeability is a measure of the ability of water to seep through earthen

material (Freeze and Cherry 1979). Although it was originally derived to measure properties of soil and bedrock aquifers, permeability has been measured using standpipes placed in streambeds in several studies to assess impacts to spawning gravel from fine sediments (Terhune 1957: Gangmark and Bakkala 1958: Barnard 1992). As permeability decreases, so does the rate of intragravel flow. The objectives of measuring streambed permeability were to: 1) compare changes in permeability within artificial redds over the winter storm season; and 2) quantify the relationship between decreasing permeability and increasing fine sediment content.

Intragravel permeability and dissolved oxygen (DO) were measured within egg baskets through DO/freeze core tubes modelled after those developed by Gangmark and Bakkala (1958) (Figures 2 and 4). Perforations at the bottom of the pipe were at the same level as the eggs in the baskets (30 to 35 cm).

Permeability testing procedures followed those of Terhune (1957) and RNP (1990), whereby the rate of water inflow was measured over time. The cap was removed from the standpipe, a taller section of pipe attached which extended above the surface water level, and a length of copper tubing inserted to 2.54 cm (one inch) below the water surface. The tubing was attached to a vacuum pump via a graduated catchment chamber. Following the development of a 2.54 cm (1 inch) head (as indicated by air bubbles entrained in the water chamber), the volume of inflow into the catchment chamber was measured over time. This procedure yielded rates of water inflow which could be related to permeability. Actual permeability values were not calculated because calibration of pipes could not be accomplished due to limited funding. Inflow rates were compared instead.

DO was measured by lowering a Yellow Springs Instrument (YSI) model probe into the pipe within egg baskets and slightly agitating the probe. DO values were recorded on a YSI electronic meter at the same level in the gravel layer as incubating eggs. DO was also measured in the surface water adjacent to the redd site for comparison to intragravel oxygen.

Initial permeability and DO concentration were measured following egg placement in February. A second series of measurements was performed in late March, just prior to removal of the hatching baskets. Timing was designed to bracket significant storms of the runoff season. Measurements were also taken just prior to and after hatching basket removal to determine if redd disturbance changed permeability rates in emergence baskets still within the redd. Disturbance greatly altered the measurements, so I was unable to conduct testing just prior to emergence basket removal as planned.

Data Analysis

Diagnostic plots of data aided in detecting outliers, necessary data transformation, and the need to pool or separate data on a reach-by-reach basis. Percentage data were corrected for non-normality using an arcsine transformation. Differences between treatment reaches were tested using students T-test or analysis of variance (ANOVA). Non-normally distributed data were analyzed using the Wilcoxon's Signed Rank test. Differences over time were statistically tested using paired T-tests or repeated measures ANOVA. Non-parametric statistics (K-W test) were used when non-normally distributed data did not meet assumptions of parametric tests. Significance was located using Student-Newman-Keuls test.

DO was compared above and below Brown Creek both prior to and after each incubation period. T-tests were used to statistically analyze data, except when assumptions of the test were violated. Due to over 16 T-tests being run for this variable, a more stringent alpha level was used to detect differences between means to reduce the chance of a type 2 error. In addition, repeated measures ANOVA were run to eliminate this problem.

Relationships between egg survival and the variables measured in the egg pocket were examined using regression analysis. The stepwise-backwards procedure was specified which was useful when running many different equations with different combinations of variables. This procedure is equivalent to choosing the variable which reduces SSE the most, and selects the 'best' model from the set of variables (the set of variables which explains the variability in the dependent variable the best) (Norusis 1986).

Under the stepwise-backwards procedure all variables are first entered into the equation, and then removed or entered step-by-step according to a criterion set by the investigator (Norusis 1986). At each step, an F-statistic is calculated for each predictor in the equation. A criterion for removal is based on a maximum P value to remove a variable. The variable with the largest P-value above the set criterion (in this case 0.11) is removed. The new regression equation is then calculated. An F-statistic is then calculated for each predictor not in the equation. The variable with the smallest P-value not in the equation is then added provided it meets the set criterion (in this case 0.10) to enter a variable. The procedure continues until no predictor can be added or removed. A final regression equation is then specified with an analysis of sums of squares and related correlation coefficients.

Single regressions were then run between each variable in the best model to determine the percent of variability attributed to that variable. Because of low sample sizes, a difference or correlation was considered significant when P

< 0.10. SPSS statistical software (Norusis 1986) was used for all statistical analyses.

1992

In general, methods used in 1992 followed those in 1991 except as follows. The first year of study suggested that proximity of redds to tributaries, the geometric mean diameter of gravel, streambed slope, flow and sediment flux all influenced fines infiltration into redds. Therefore, I attempted to keep most of these variables constant when selecting sites for artificial redd construction. Sediment flux could not be held constant because it increased downstream as a result of each tributary providing more sediment to the mainstem (RNP 1991a). Greater proportions of sampling locations were also placed in stream reaches of Prairie Creek most used by natural spawners (Figure 5).

In addition, the stream section above Brown Creek on Prairie Creek (control reach during 1991) was more affected by sediment inputs from the Bypass (from the affected tributary, Ten Tapo Creek) than previously thought. The strata immediately below Brown Creek was eliminated from sampling, because the gradient was steeper than the other two and because very few natural spawners had used this reach over the past (RNP 1991a). Thus, five sampling sites on Lost Man Creek were added to supplement control reach

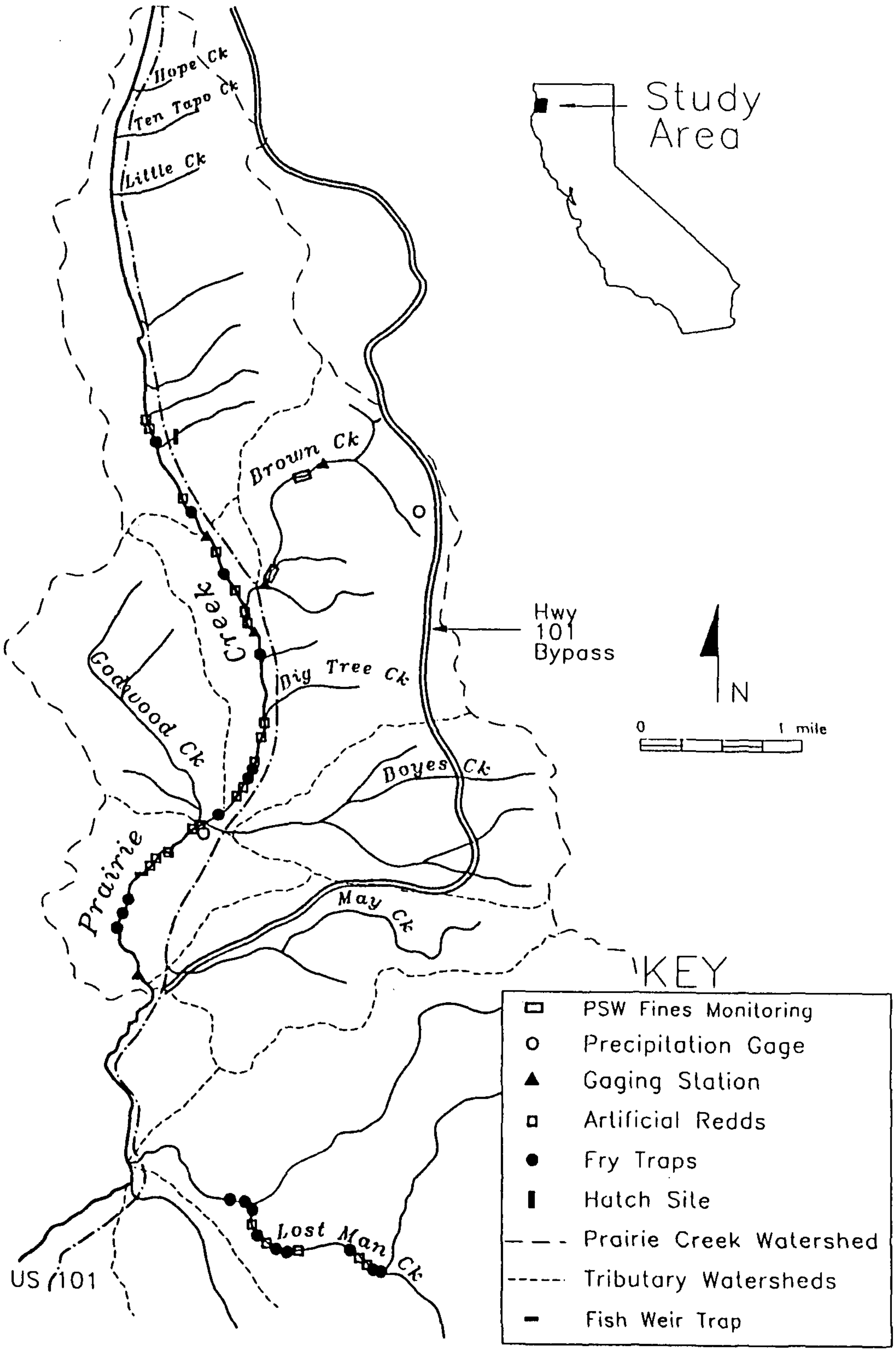

Figure 5. Location Map and 1992 Study Sites, Prairie Creek, CA.

locations. Lost Man Creek was less than ideal in that it had been subjected to sedimentation from past timber harvest activities, and differed geologically from Prairie Creek. However, Lost Man Creek was not impacted by the Bypass and was the next best control reach available. Particle size distribution in each stream was examined for comparison purposes.

Survival During Incubation

Sampling locations on Prairie Creek were stratified by the larger tributary Brown Creek as before, and further stratified by smaller tributary streams (Figure 5). Five locations were identified above Brown Creek (the control), five on Lost Man Creek (additional control), and five each below Big Tree and Boyes Creeks (treatment reaches). Each set of 5 was split into a substrata of 2 redds that were directly influenced by tributary inputs and a substrata of 3 redds that were not immediately downstream.

Survival to Hatching. Results from 1991 suggested that egg mortality occurred prior to the hatching stage, thus baskets designed to determine egg survival to emergence were omitted from the study in 1992. Instead, two baskets testing survival to hatching were placed in each redd to achieve replication within riffles. The two were placed side-by-side to reduce spatial variation. Predatory worms found in emergent baskets were weighed.

Natural Emergence Survival. Natural redds were again capped on Prairie and Lost Man Creeks, however, sample sizes were increased. Ten natural redds on Prairie Creek (5 below Brown Creek and 5 above) and nine natural redds on Lost Man Creek were capped (Figure 5). Redds were capped earlier than in 1991 to prevent superimposition of redds by other spawners (thus preventing multiple redds being capped).

Controls. Sample size to determine handling mortality was increased. Several batches of eggs (300 from fish 1, and 200 each from the other three fish), used in artificial redds, were placed in identical egg baskets then incubated in a hatch trough surrounded with sterilized stream gravel. Percentages of eggs surviving to the eyed stage in these baskets were then compared to percentages of remaining eggs surviving to eyed stage in the mitigation hatch troughs. Mortality due to handling, could then be separated from mortality due to non-fertilization of eggs.

Upon basket removal, dead eggs and live alevins were enumerated and divided by the number of eggs placed in each basket, to calculate percent survival-to-hatch (STH). Percent data were arcsine transformed and analyzed using repeated measures ANOVA and analysis of co-variance (ANCOVA).

Physical Variables Measured

Methods used to determine the percentage of fine sediment infiltrating stream gravel within hatching baskets in 1992 did not appreciably differ from those used in 1991. However, when sieving gravel, the 4 mm size class was omitted to reduce redundancy. The percentage of organic matter within samples was not determined in 1992 given 1991's analysis of this factor. Due to difference in timing of redd creation and accumulations of fines in fry traps, McNeil samples of natural redds were not taken during the second year of study. Repeated measures ANOVA was used to analyze differences between treatments.

Results from the 1990 study on Prairie Creek indicated that permeability may be affected by changes in hydraulic pressure with changing discharge (Klein 1991). Thus, permeability measurements were taken under similar flow conditions to control possible effects of discharge upon permeability measurements. Discharge was estimated for each location from continuous stage recorders operated by RNP personnel. In addition, replicate measurements were taken in each redd at the same discharge to control variation within testing procedures and to obtain a reliable average.

Repeated measures ANOVA was used to analyze differences between initial and final inflow measurements and differences between treatment reaches. Replicate measurements within sites enabled control between basket variation (dummy variable 'TESTS'), and replicate baskets enabled control over site variation (dummy variable 'SITE'). This enabled analysis of the within-subject factor (dummy variable 'TESTS WITHIN SITE') since each set of three replicate 'TESTS' was nested within each 'SITE', thus differences between treatments could be emphasized over differences between baskets and between sites.

Methods used in 1992 to measure DO concentrations were changed slightly as data from 1991 were suspect. DO was measured prior to measuring permeability, as the process of measuring permeability could slightly increase DO levels through drawing surface water into the pipes. Concentrations were again recorded from a YSI dissolved oxygen meter. DO was also measured in the surface water adjacent to the redd site for comparison to intragravel water. Repeated measures ANOVA was used to analyze differences over time (variable 'TIME') and between reaches (variable 'TREATMENT').

Data Analysis

Due to a different but much improved experimental design of the second year of study, data were analyzed differently. Thus, the experiment was designed for a nested analysis. In this model, the hatching baskets were the replicates, (two within each artificial redd), the redds were the experimental units (ten within each reach), and the reaches were the groups or treatments (two). All effects were fixed, except the artificial redds which were randomly picked. This model determined if more variability existed within redds, than between redds (or within reaches than between baskets etc.), as well as whether affected reaches were significantly different than control reaches.

Different models were run for each subset of variables which included the dependent variable, survival, two independent variables, final inflow rate and percent fines, and the categorical variable, fish stock. I replaced this categorical variable with a quantitative measure of fertilization rate (variable 'ATFERT'), to classify data because the allocated codes (integers for fish one through four) defined a metric for the classes of the qualitative variable which may not be reasonable for regression analysis (Neter et al. 1990).

Therefore, I computed the quantitative variable ATFERT from the overall survival rates obtained for each fish from the nine control baskets incubated in hatch troughs (percentages are arcsine transformed). The order of values in ATFERT corresponded to the ordering in the categorical fish identification variable 'FISHID', only the magnitudes are different. Use of a quantitative variable versus a categorical or indicator variable defined four separate regression functions for the model, with the Y-intercept as the measured difference between each fish. Thus, these percentages more readily approximated differences between fish than the allocated codes, as differences were far less arbitrary.

RESULTS

1991

Survival During Incubation

Eggs from no more than three or four female coho salmon were intended to be used, to reduce variation in fecundity and survival. Three females were spawned to obtain 4000 eggs for the study; 36%, 43% and 79% of the eggs from each of the three fish were used. To determine infertility, the remaining eggs (1722, 2024 and 435 eggs respectively) from each female were incubated in hatch troughs at the PCFFA rearing site located on a small unnamed tributary to Prairie Creek (Figure 1). These eggs were tracked to the hatched stage to determine the percentage of eggs fertilized and the percentage of fertilized eggs that were viable.

Survival-to-Hatching. Fertilization rates of the three females were 90%, 68% and 92%. Percent viability of these eggs to hatching was 87%, 67% and 92%, respectively. Percentage of eggs surviving to the eyed stage was 98% for the handling control basket; handling mortality was determined to be low (2%).

Fertilized eggs were incubated in redds of each reach from January 11 and 12 to approximately March 28, 1991 (75 days or 1148 degree days after fertilization). The remaining eggs from each stock incubated in hatch troughs hatched in 60 days (950 degree days) at similar water temperatures.

Mean percent hatching survival was 0.7% (SE = 0.4) in the affected reach and 9.0% (SE = 4.6) in the control reach (Table 1). The difference between reaches was statistically significant (P = 0.09). Survival ranged from 0 to 3% in the affected reach and from 0 to 45% in the control reach (Appendix A and Figure 6). Sixty percent of all baskets (12 of 20) experienced 100% mortality. Sixty-four percent of those (7 of the 12) occurred below Brown Creek (the affected reach). Thus, 70% of redds below Brown Creek (7 of 10) and 50% redds above Brown Creek (5 of 10) had 100% mortality.

Alevins from artificial redds in the affected reach appeared smaller, weaker, and had reduced swimming ability compared to those in the control reach. Several embryos were also found which were severely undeveloped (still in the egg stage, Figure 6, Site bb4) and many fry appeared very recently hatched. Fry in the control reach appeared generally more healthy and stronger with no sign of under-development.

Hatching in artificial redds of both reaches was delayed by 13 days (196 degree days) when compared to eggs incubated in hatch troughs under similar water temperatures. Most dead eggs had reached the eyed stage, although the majority of eggs were missing or decomposed. Large masses of several hundred oligochaete worms (Haplotaxia

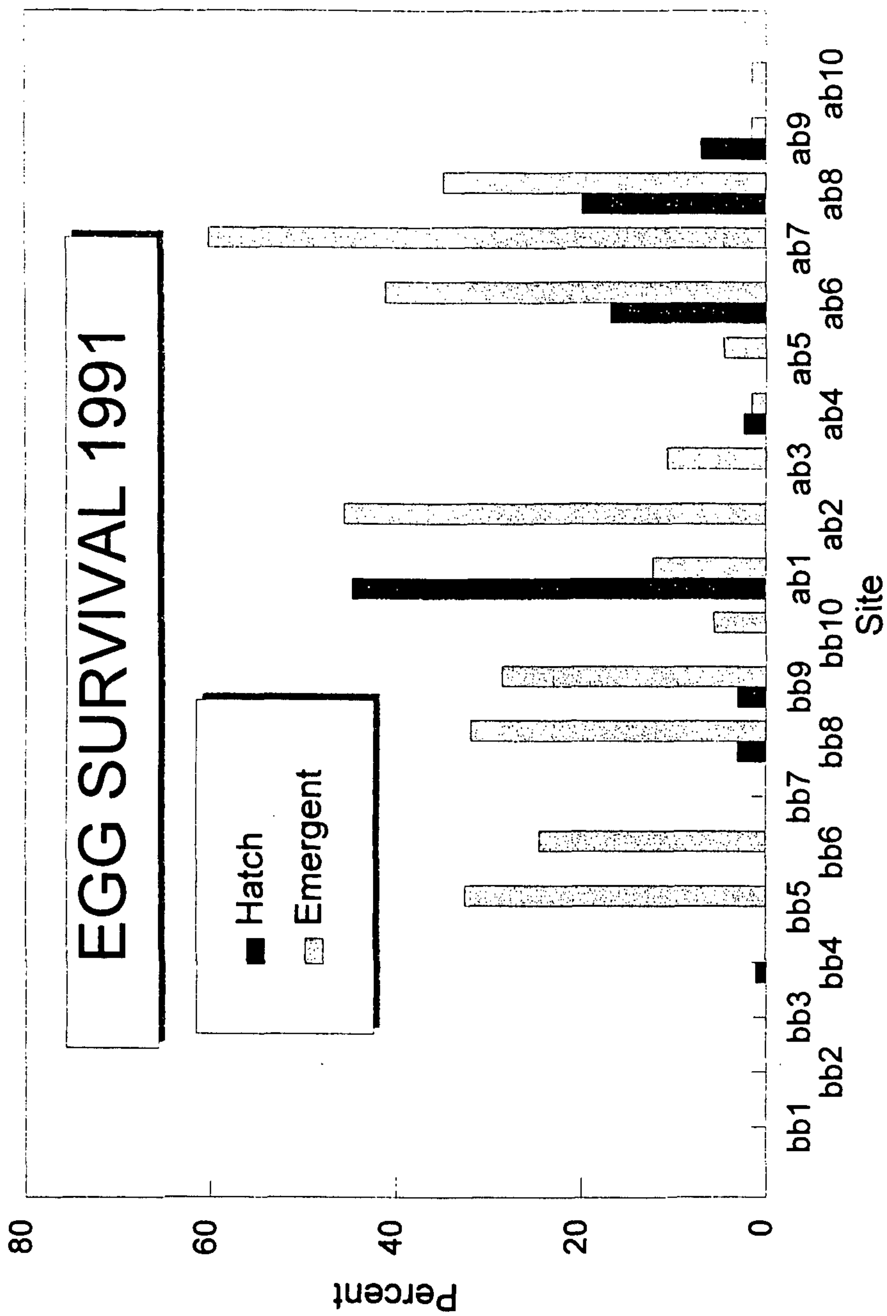

Figure 6. Survival to Hatch and Emergence within Artificial Redds (bb# = Below Brown Creek, ab# = Above Brown Creek) on Prairie Creek, CA 1991.

Table 1. Mean Percent Egg Survival and Percent Worm Infestation in Sites with and without Worms in Affected (Below Brown Creek, n = 10) and Control (Above Brown Creek, n = 10) Reaches of Prairie Creek (Standard error is in parenthesis).

	MEAN % SURVIVAL	% WORM INFESTED	MEAN % SURVIVAL (INFESTED)	MEAN % SURVIVAL (NON-INFESTED)
PRAIRIE CREEK (REACHES POOLED)				
ALL	11.1 (2.6)	62	7.3 (2.6)	17.1 (5.2)
HATCH	4.9 (2.4)	55	2.0 (1.6)	8.5 (5.0)
EMERGENCE	17.6 (4.3)	68	11.9 (4.3)	30.0 (8.7)
PRAIRIE CREEK (CONTROL REACH)				
ALL	15.9 (4.4)	47	11.1 (4.8)	19.3 (7.1)
HATCH	9.0 (4.6)	40	4.2 (4.2)	12.3 (7.1)
EMERGENCE	23.5 (7.3)	56	18.5 (8.1)	29.8 (13.7)
PRAIRIE CREEK (AFFECTED REACH)				
ALL	6.5 (2.7)	75	4.4 (2.6)	12.7 (7.2)
HATCH	0.7 (0.4)	70	0.6 (0.4)	1.0 (1.2)
EMERGENCE	12.3 (4.7)	80	7.8 (4.6)	30.2 (1.6)

ichthyophagous), thought to be predacious (Briggs 1953), were found surrounding dead eggs in baskets.

Fifty-five percent of all baskets (11 of 20) were infested with worms. Seven of ten below Brown Creek and 4 of 10 above Brown Creek were infested. Mean survival in all worm-infested redds was 2.0% (SE = 1.6) and in all non worm-infested redds was 8.8% (SE = 5.1) (Table 1).

When all worm-infested redds were excluded, mean survival in redds below Brown Creek was 2.5% (n = 3) and above Brown Creek was 12.7% (n = 6). Thus when worm-infested redds were excluded, survival in the affected reach about doubled and survival in the control reach increased about 50%.

Survival-to-Emergence. Fry emergence began in mid-April, 1991. Timing of initial and peak emergence was approximately the same for both reaches at 95 and 108 days respectively, with the affected reach slightly delayed (by several days) compared to the control reach. Fry from both reaches generally appeared in healthy condition. However, fry held at the PCFFA site began emerging from gravel on March 14, after 62 days (936 degree days). Fry emergence in artificial redds started after 95 days (1462 degree days).

Ten affected sites were compared with nine control sites (Site ab10 was destroyed by a bear). Mean percent emergence survival was 12.3% (SE = 4.7) in the affected reach and 23.5% (SE = 7.3) in the control reach. The difference between reaches was not statistically significant ($P < 0.1$). Survival ranged from 0 to 32% in the affected reach and from 1.5% to 60% in the control (Appendix A and Figure 6). A larger percentage of emergence baskets were infested with oligochaete worms than were hatching baskets (Table 1). However, only half the baskets above Brown Creek were placed in the stream just prior to the largest storm of the year. The other half were placed in the stream several days later. Thus baskets in the control reach were subjected to different storms, potentially causing temporal differences in fines accumulation and survival rates. When the five pre-storm baskets were removed from statistical analysis, mean percent emergence survival increased to 38.6% (SE = 7.8) in the control reach. This difference between reaches was statistically significant ($P = 0.04$). Survival increased to a range of 12% to 60% in the control. Mean percent emergence survival in the pre-storm baskets above Brown Creek was 4.0% (SE = 1.8).

No entrapped fry were in the baskets upon removal. Some oligochaete worms were found surrounding dead embryos in emergent baskets, although worms appeared more dispersed than those in hatching baskets.

Average worm mass per emergent basket was 22.0 g in the affected reach and 14.8 g in the control (averaging about 0.3 g/worm). Sixty-eight percent (13 out of 19) of all emergence baskets were infested with worms (Table 1). Eight out of ten emergence baskets in the affected and 5 out of 9 baskets in the control reach were infested at varying levels. Worms appeared to be more abundant in the affected reach than the control reach.

Mean egg survival-to-emergence in redds was 11.9% (SE = 4.3) in all worm-infested redds and 30.0% (SE = 8.7) in all redds without worms. When separated by reach, survival in worm-infested redds was 7.8% (SE = 4.6) in the affected and 18.5% (SE = 8.1) in the control. When worm-infested baskets were excluded from analysis, mean egg survival-to-emergence increased 2 1/2 times to 30.2% (SE = 1.6, n = 2) in the affected reach and 1 1/5 times to 29.8% (SE = 13.7, n = 5) in the control reach.

Natural Emergence Survival. Redds trapped on Prairie and Lost Man Creeks represented 9.1 and 10.7% of the redds counted during 1991 surveys in each stream respectively. Only one trap out of ten on Prairie Creek produced significant numbers of fry (Figure 7). Three traps below Brown Creek on Prairie Creek produced 2, 37 and 3671 (coho and steelhead) fry, for a total of 3710. No traps above Brown Creek produced fry. All three traps on Lost Man Creek produced significant numbers of fry: 219, 208 and 804 (coho and steelhead) for a total of 1231 fry. Redds producing the most fry on Prairie and Lost Man Creeks were those superimposed by other spawning fish, as was noted by multiple peaks of emergence. Unfortunately, fry were too

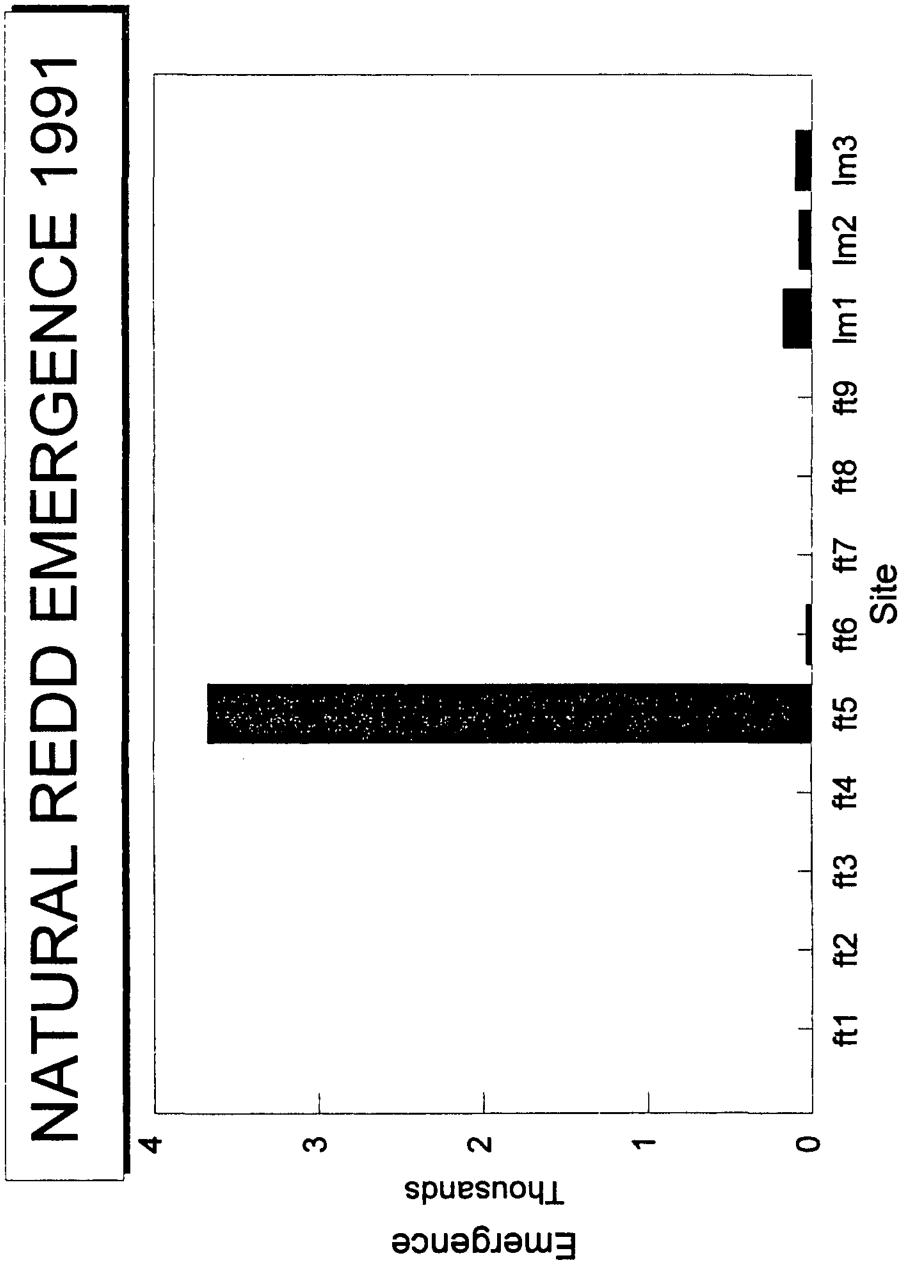

Figure 7. Numbers of Fry Emerging from Natural Redds on Prairie (ft#) and Lost Man (lm#) Creeks, CA 1991.

small to be identified accurately. Size distribution of fry emerging from natural redds was variable because some fry stayed underneath the trap's netting until flows flushed them into the capture bottle. Consequently, size distribution data could not be statistically analyzed and no distinguishing trends were apparent. Juvenile tailed frogs (Ascaphus truei), pacific giant salamanders (Dicamptodon tenebrosus), pacific lamprey ammocoete (Lampetra tridentata) and sculpins (Cottus spp.) were also found occasionally in traps. Emergence timing in natural redds on Prairie Creek approximated the timing of artificial redds at 94 days (degree days = 1604).

However, peak emergence on Lost Man Creek redds occurred 28 days earlier (at 66 days) than the peak on Prairie Creek. Lost Man Creek temperatures were not monitored, although temperatures tend to be higher (pers. comm., S. Sanders, 1991, Prairie Creek Fish Hatchery, Orick, CA 95555). Daily average temperatures were collected between January 11 and July 22, and ranged from 4.5 to 15.5° C. Stream temperatures collected from the unnamed tributary at the PCFFA Hatchery station, on the average were lower than the two stations monitored on Prairie Creek (Figure 8). Fry in hatch troughs emerged after 62 days (936 degree days). One redd was dug up in search of oligochaete worms. Approximately 5 gm of worms were discovered. Worms were also

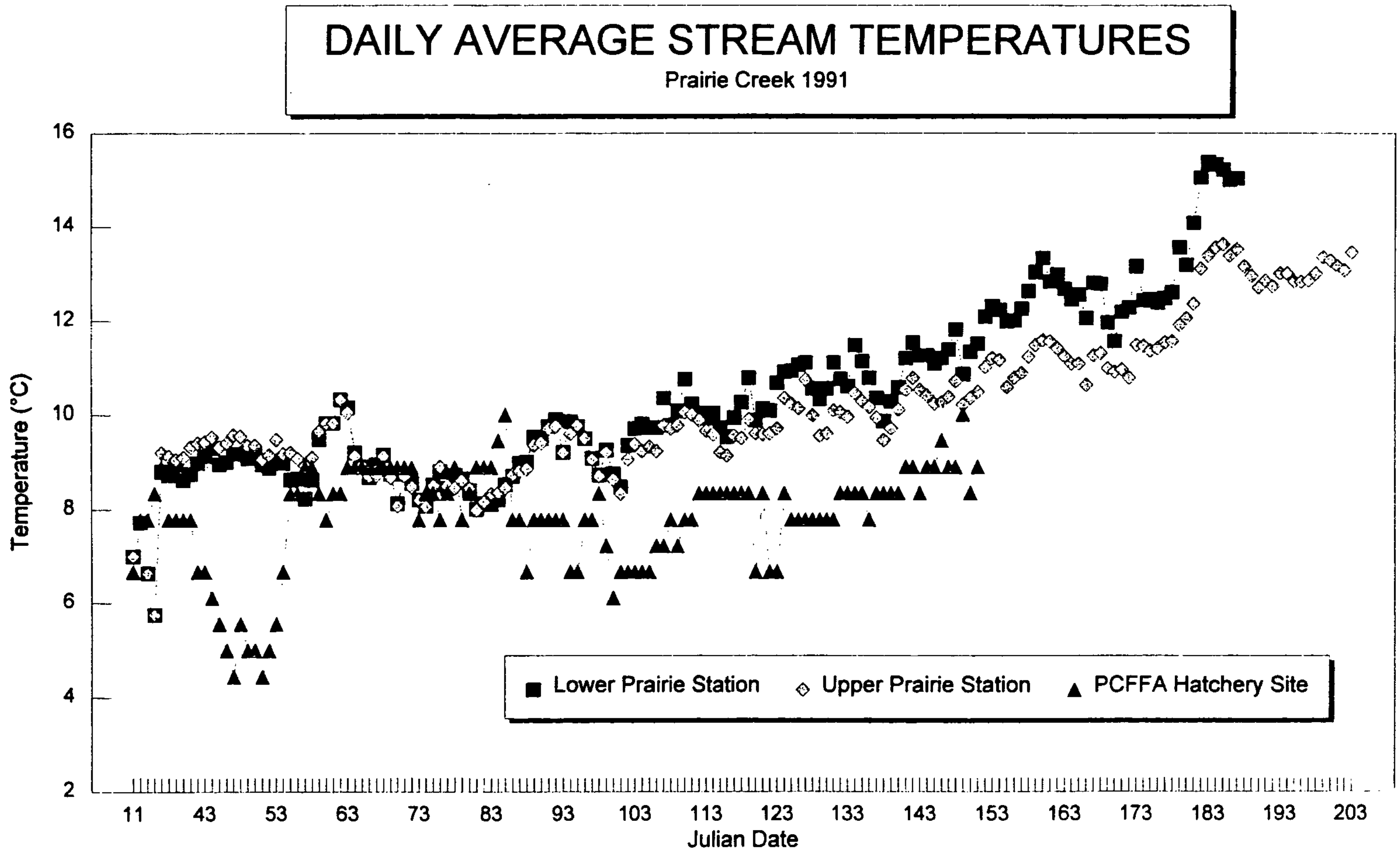

Figure 8. Stream Temperatures Measured in Prairie Creek, CA between January 11 and July 22, 1991.

observed along the stream bottom as well as in redds made by spawners during carcass surveys.

Physical Measurements

Substrate Composition. Even after adjusting volumetric measur[illegible] ater gained during analysis, ratios of weight [illegible] variable from sample to sample; thus, both [illegible] e measurements were presented.

FINES < 1 MM NOT ACCUMULATING!

[illegible] ive percent fines (< 1.00 mm) in hatching [illegible] by weight and 11.36% by volume in the [illegible]ected reach and 2.60% and 12.28% respectively in the control reach. The difference between reaches was not statistically different by either weight or volume analysis using T-tests (Table 2). Percent fines ranged from 0.89% to 12.37% by weight and from 4.93% to 17.75% by volume in the affected reach (Figure 9). In comparison, percent fines in the control reach ranged from 1.29% to 4.72% by weight and from 3.88% to 21.69% by volume.

The fines < 4.75 mm that infiltrated back into the redd over the incubation period were largely composed of particles < 0.50 mm (87% in the affected reach and 91% in the control). Statistics for other size classes are presented in Table 2. Raw data are presented in Appendix A. High amounts of worms were found in 3 of 10 baskets of both reaches.

Similar to hatching basket results, fine sediment < 0.50 mm dominated the fine fraction < 4.75 mm in the

Table 2. Comparison of Mean Percent Fines in Hatching Baskets of Artificial Redds on the Affected and Control Reaches of Prairie Creek, 1991.

PARTICLE SIZE (mm)	AFFECTED REACH MEAN (S.E.)	CONTROL REACH MEAN (S.E.)	P
BY WEIGHT			
< 4.75	4.81 (0.65)	3.86 (0.45)	0.26
< 1.00	2.79 (0.41)	2.60 (0.22)	0.68
< 0.50	1.91 (0.34)	1.81 (0.12)	0.85
BY VOLUME			
< 4.75	13.12 (0.86)	13.48 (0.74)	0.74
< 1.00	11.36 (0.76)	12.28 (0.72)	0.41
< 0.50	10.76 (0.71)	11.71 (0.76)	0.38

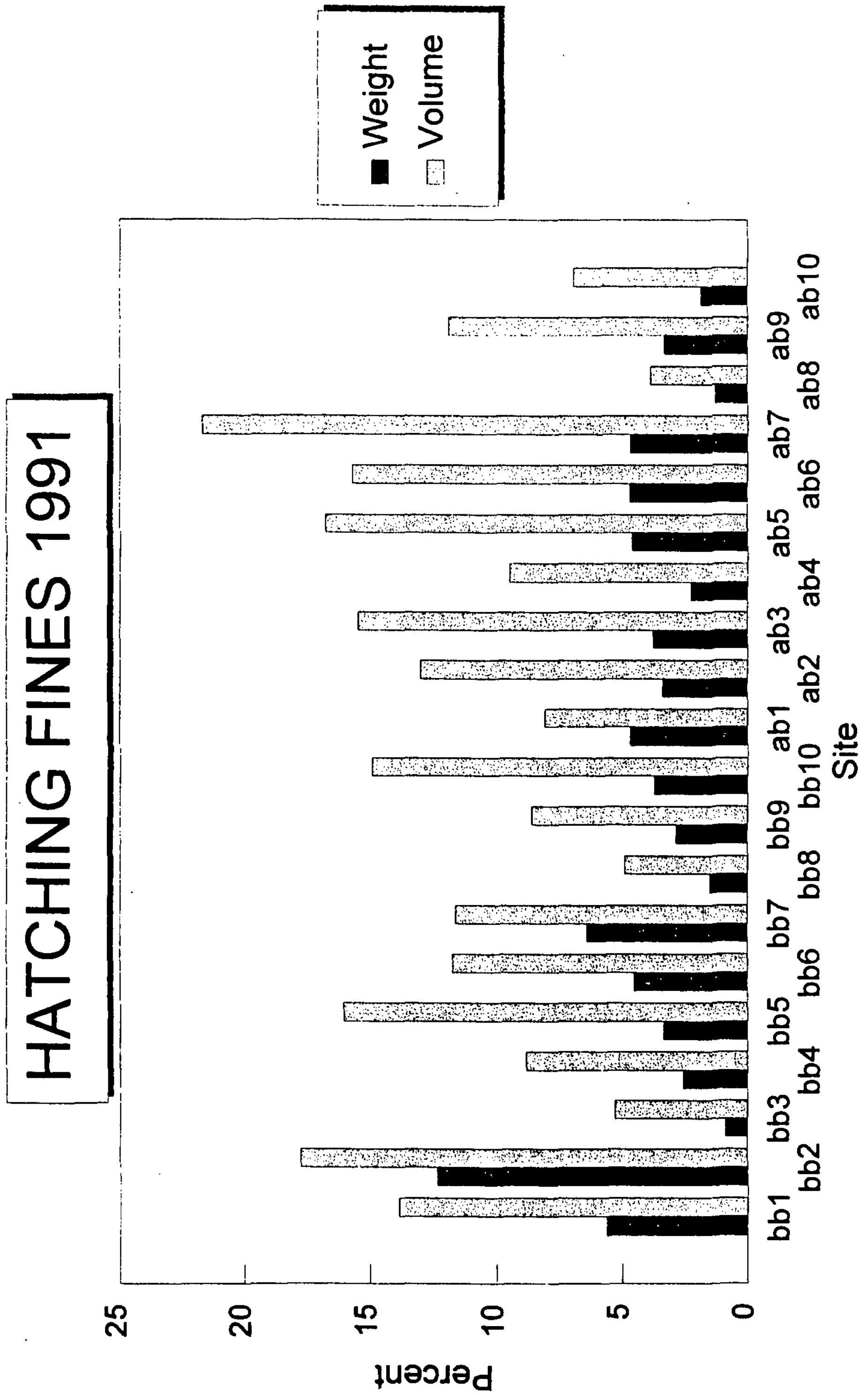

Figure 9. Percent Fines (< 1 mm) by Weight and Volume from Hatching Baskets within Artificial Redds (bb# = Below Brown Creek, ab# = Above Brown Creek) on Prairie Creek, CA 1991.

emergence baskets, comprising 73% and 79% in the affected and control reach respectively.

Weight to volume ratios also varied. Mean percent fines (< 1.00 mm) by weight was 4.51% (SE = 0.90) in the affected reach and 2.29% (SE = 0.39) in the control (all sites). This difference was statistically significant ($P < 0.05$). Percent fines by weight ranged from 1.36% to 10.16% in the affected reach and from 1.65% to 6.18% in the control (Figure 10 and Appendix B).

Means by weight for other size classes are presented in Table 3 for comparison to hatching results, and were statistically significant as well ($P < 0.10$). Raw data are presented in Appendix B. Mean percent fines < 1.00 mm by volume was 13.58% (SE = 0.97) in the affected reach and 12.18% (SE = 1.67) in the control (all sites). This difference was not statistically significant ($P > 0.1$). Percent fines by volume ranged from 9.73% to 21.93% in the affected reach and from 6.94% to 24.22% in the control (Figure 10 and Appendix B). No difference was detected for means of 4.75 and 0.50 mm size classes by volume either (Table 3).

In 1991, due to the continuing drought, fish entered the stream sporadically instead of in distinct runs. Because I experienced difficulties in obtaining ripe females for spawning, temporal differences existed between emergent baskets placed in the control reach. Emergent baskets in

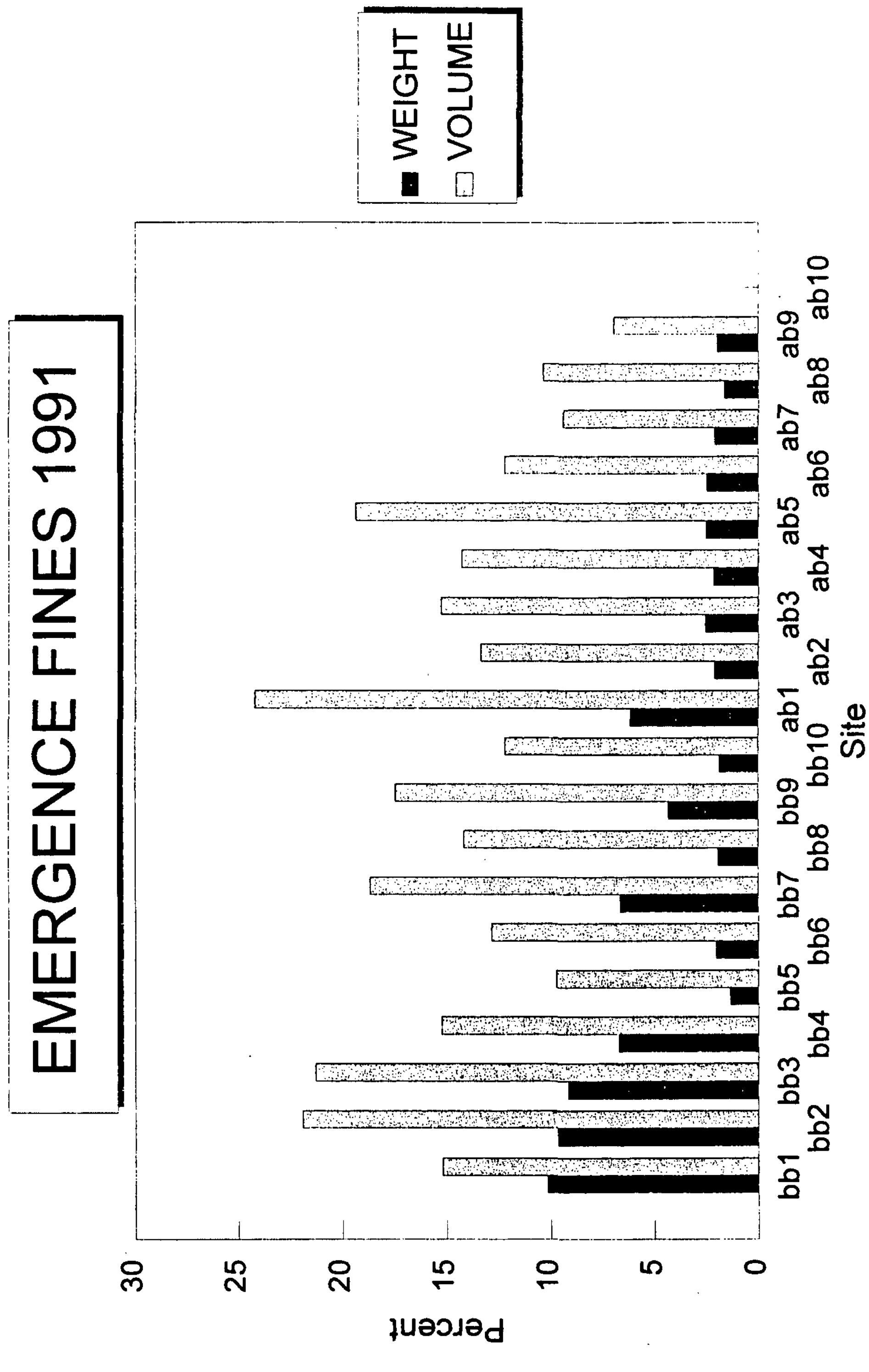

Figure 10. Percent Fines (< 1 mm) by Weight and Volume from Emergent Baskets within Artificial Redds (bb# = Below Brown Creek, ab# = Above Brown Creek) on Prairie Creek, CA 1991.

Table 3. Comparison of Mean Percent Fines in Emergence Baskets of Artificial Redds on the Affected and Control Reaches of Prairie Creek, 1991.

PARTICLE SIZE (mm)	TEST	AFFECTED REACH MEAN	(S.E.)	CONTROL REACH MEAN	(S.E.)	P
BY WEIGHT						
< 4.75	T-Test	8.48	(1.93)	3.96	(0.66)	0.051
< 1.00	T-Test	4.51	(0.90)	2.29	(0.39)	0.048
< 0.50	T-Test	2.81	(0.43)	1.70	(0.14)	0.033
BY VOLUME						
< 4.75	K-W	16.75	(1.62)	14.27	(2.31)	> 0.10
< 1.00	K-W	13.58	(0.97)	12.18	(1.67)	> 0.10
< 0.50	K-W	12.35	(0.81)	11.25	(1.27)	> 0.10

sites ab3,4,5,9 and 10 were placed in the stream just prior to the largest storm of the year on January 12 (Figure 10), whereas the other baskets were not placed until one week later on January 18. Only half of the baskets in the control reach experienced the severe sedimentation associated with the January 12 storm. Data were also analyzed to determine if temporal differences between placement of baskets were related to infiltration of fines, survival or permeability.

Analysis of percent fines from control baskets exposed to the storm (12.4% by volume) versus control baskets that were not (12.0% by volume) showed no significant difference ($P > 0.10$). Each freeze core sample was analyzed to determine where the fines occurred vertically within infiltration bags. Freeze cores were not obtained for all baskets; 12 cores (6 from each reach) were analyzed (Table 4). One basket was destroyed by a bear, and three cores failed due to experimenter error. Four other cores were not complete samples presumably due to improper freezing.

Cores that did freeze well often contained dead eggs, oligochaete worms and fine sediment, indicating samples were obtained from the egg pocket. Most fines (73.6% and 81.5%) occurred in the bottom strata (the location of the egg pocket) of baskets below and above Brown Creek respectively (Table 4 and Figure 11).

Mean percent fines by weight was 4.43% in the affected reach and 1.82% in the control. This difference was

Table 4. Distribution of Fine Sediment < 1.00 mm by Weight within Freeze Cores Sampled from Affected (n = 6) and Control (n = 6) Reach Emergent Baskets in Artificial Redds, Prairie Creek , 1991.

SITE	% FINE SEDIMENT IN STRATUM (cm) BOTTOM 20-30	MIDDLE 10-20	TOP 0-10	% DISTRIBUTION ACROSS ALL STRATA (cm) BOTTOM 20-30	MIDDLE 10-20	TOP 0-10
AFFECTED REACH						
bb1[1]	8.96	5.98	6.33	42.13	28.11	29.76
bb2	6.83	0.59	0.06	91.31	7.89	0.80
bb6	2.22	0.21	0.00	91.36	8.64	0.00
bb7	4.08	1.14	1.57	60.08	16.79	23.12
bb9	3.28	1.38	*	70.39	29.61	*
bb10	0.81	0.10	0.03	86.17	10.64	3.19
Mean	4.36	1.57	1.60	73.57	16.95	11.37
CONTROL REACH						
ab4[2]	3.09	0.06	*	98.10	1.90	*
ab5	2.04	0.13	*	94.01	5.99	*
ab6	1.70	0.09	*	94.97	5.03	*
ab7	0.52	0.36	0.23	46.85	32.43	20.72
ab8	0.74	0.34	0.14	60.66	27.87	11.48
ab9	2.41	0.14	*	94.51	5.49	*
Mean	1.62	0.20	0.19	78.92	14.64	16.10

* = top strata data not included due to incomplete freezing
[1]bb# = sampling locations below Brown Creek
[2]ab# = sampling locations above Brown Creek

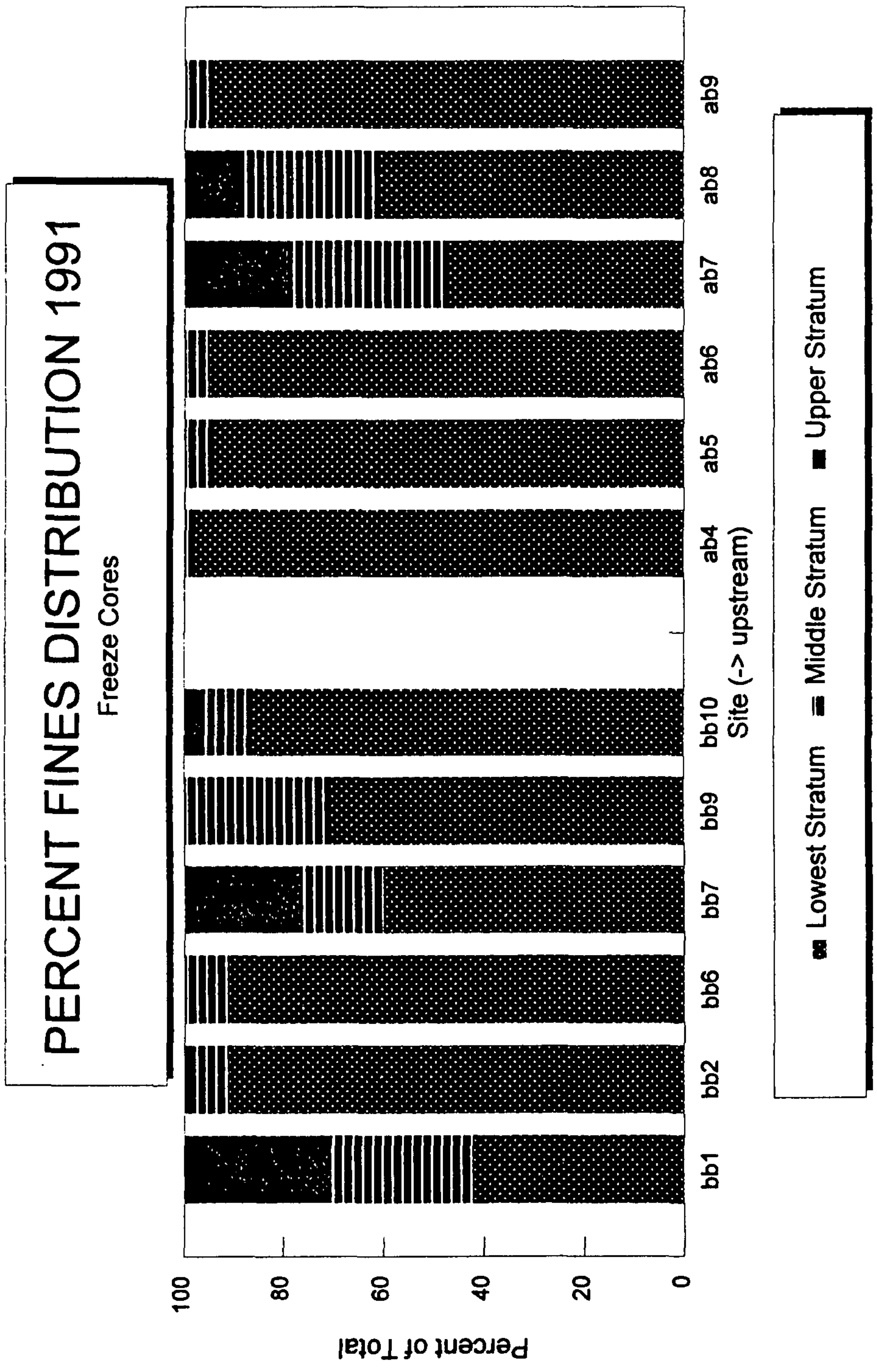

Figure 11. Distribution of Fines (< 1 mm) in Freeze Cores within Emergent Baskets, as Percent of Total, (bb# = Below Brown Creek, ab# = above Brown Creek) Prairie Creek, CA 1991.

statistically significant at P < 0.06 (K-W). Mean percent fines < 0.50 mm by weight was 2.73% in the affected reach and 1.32% in the control, but not statistically significant (P = > 0.10, K-W).

Organic Matter Component. Mean percent organic matter component in hatching baskets was 12.30% in the affected reach and 13.61% in the control reach (Table 5). No significant difference existed between reaches (P > 0.10). All natural redds except one were sampled for sediment in mid-July using a McNeil sampler. Mean percent fines < 1.00 mm by weight was 4.83% in the affected reach, 4.12% in the control reach of Prairie Creek, and 4.61% in Lost Man Creek (Table 6).

"True" particle size distribution curves were determined by removing the organic matter component from each sample. Removing this component, reduced percent fines slightly (by an average of 1%). Mean cumulative percent fines < 0.50 mm in hatching baskets was 1.83% in the affected reach and 1.53% in the control, after correction (Table 5). No significant difference existed between reaches (P > 0.10). Mean percent organic matter in hatching baskets with worms was 13.70% versus 12.31% in sites without worms (Table 5). This difference was not statistically significant (P > 0.10).

Table 5. Percentage of Fines < 0.50 mm Composed of Organic Matter, and Percentage of Gravel Sample Composed of Inorganic Fine Sediment < 0.50 mm in Artificial Redds of Affected (n = 10) and Control Reaches (n = 9) of Prairie Creek, 1991. Reach data are also pooled (with and without worms).

		AFFECTED REACH		**CONTROL REACH**		
		Mean	(S.E.)	Mean	S.E.	P
Organic	(%)	12.30	(1.40)	13.61	(1.54)	> 0.10
Inorganics	(%)	1.83	(0.36)	1.53	(0.17)	> 0.10
		AFFECTED AND CONTROL REACHES POOLED				
		With Worms (n = 11)		Without Worms (n = 7)		
Organic	(%)	13.70	(1.57)	12.31	(1.32)	> 0.10

Table 6. Comparison of Percent Fine Sediment Found in Natural Redds on the Affected (n = 6) and Control (n = 3) Reaches of Prairie and Lost Man (n = 3) Creeks, 1991.

Particle Size (mm)	AFFECTED REACH Prairie Creek Mean (S.E.)	CONTROL REACH Prairie Creek Mean (S.E.)	CONTROL REACH Lost Man Creek Mean (S.E.)	P
By Weight				
< 4.75	15.4 (3.3)	11.3 (5.8)	17.4 (4.6)	0.465
< 1.00	4.8 (3.0)	4.1 (2.2)	4.6 (0.2)	0.755
< 0.50	3.2 (1.0)	2.8 (1.4)	3.2 (0.1)	0.839
By Volume				
< 4.75	18.8 (4.1)	16.8 (7.7)	17.1 (4.1)	0.714
< 1.00	9.2 (2.6)	8.1 (3.3)	10.1 (1.4)	0.812
< 0.50	8.0 (2.5)	6.6 (2.6)	9.2 (1.5)	0.894

Mean percent fines < 1.00 mm by volume was 9.2% in the affected, 8.1% in the control reach of Prairie Creek, and 10.1% in Lost Man Creek. Percentages for < 4.75 and < 0.50 mm size classes are also presented in Table 6. There were no significant differences between the reaches for <u>any</u> of these size classes (K-W, $P > 0.1$). Percentages of fine sediment by weight in natural redds were comparable to percentages in artificial redds except that fines < 1.00 mm were slightly higher in hatching baskets of the affected reach. Percentages of fine sediment by volume in natural redds were lower than artificial redds. Data from natural and artificial redds were not statistically compared due to differences in the sampling techniques used (i.e., infiltration bag vs. McNeil sampler).

<u>Permeability and Dissolved Oxygen</u>. Water inflow rates were measured during the same time period for both hatching and emergent baskets (Figures 12 and 13). Inflow rates significantly decreased over time for both sets of baskets in the affected reach ($P = 0.002$ and $P = 0.012$ respectively) (Table 7). However, inflow rates did not significantly change for either sets of baskets in the control reach (Figure 13). Mean change in inflow rates of hatching baskets was -24.1 cm^3/sec in the affected reach and +1.4 cm^3/sec in the control reach. This difference was statistically different ($P = 0.048$).

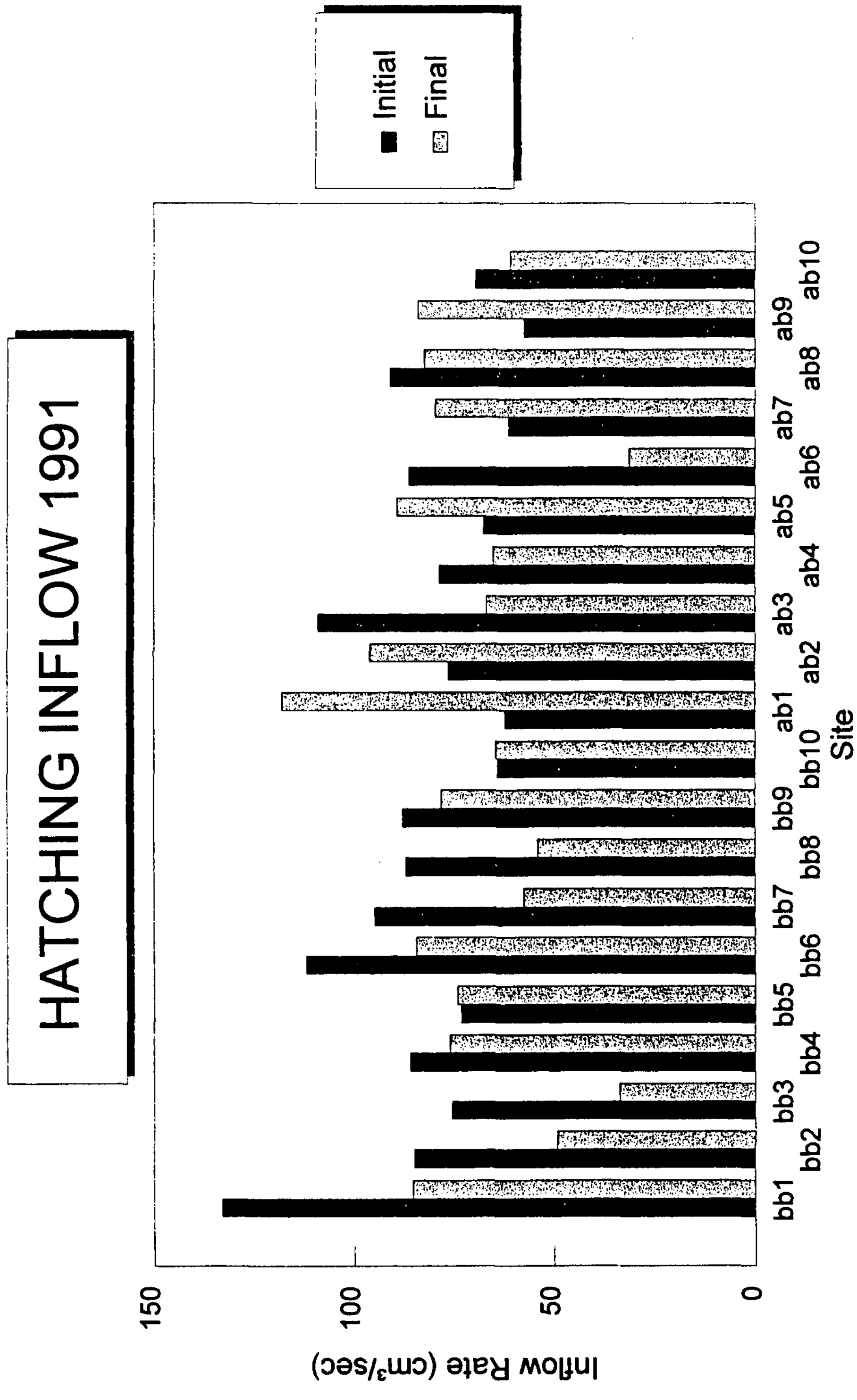

Figure 12. Comparison of Inflow Rates over the Incubation Period from Hatching Baskets within Artificial Redds (bb# = Below Brown Creek, ab# = above Brown Creek) on Prairie Creek, CA 1991.

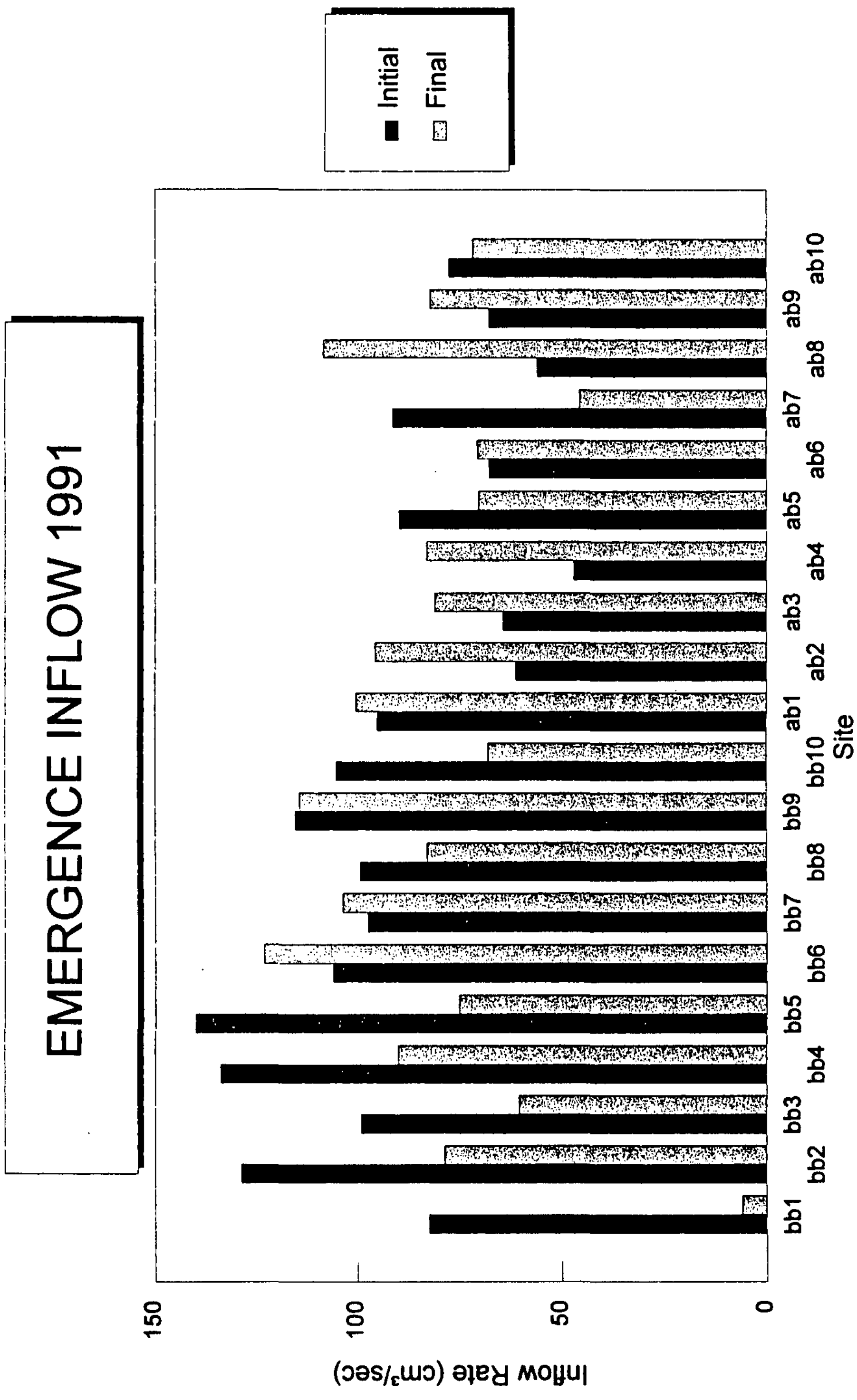

Figure 13. Comparison of Inflow Rates over the Incubation Period from Emergence Baskets within Artificial Redds (bb# = Below Brown Creek, ab# = above Brown Creek) on Prairie Creek, CA 1991.

Table 7. Comparison of Mean Inflow Rates in Hatching and Emergence Baskets (n = 10) of Affected and Control Reaches of Prairie Creek, 1991, using Repeated Measures ANOVA. Mean change in inflow rate (cm^3/sec) was compared using the T-test.

	HATCHING BASKETS				**EMERGENCE BASKETS**			
	AFFECTED REACH		CONTROL REACH		AFFECTED REACH		CONTROL REACH	
	Mean	(S.E.)	Mean	(S.E.)	Mean	(S.E.)	Mean	(S.E.)
Initial	89.8	(6.3)	75.8	(5.0)	110.8	(5.8)	71.7	(5.4)
Final	65.7	(5.3)	77.2	(7.3)	80.2	(10.9)	80.9	(6.0)
Change	-24.1	(5.7)	+1.4	(10.6)	-30.5	(9.8)	+9.1	(9.1)
P	< 0.005		> 0.05		< 0.05		> 0.05	

Mean change in inflow rates of emergent baskets was -30.5 cm^3/sec in the affected reach and +9.1 cm^3/sec in the control reach. This difference was also statistically significant ($P = 0.008$). Mean inflow change for baskets which underwent similar storms (Figure 14) was -30.5 cm^3/sec (SE = 9.8) in the affected reach ($n = 10$) and +9.8 cm^3/sec (SE = 16.7) in the control ($n = 5$). This difference was still statistically significant ($P = 0.041$). In 1991, only very small changes were measured in DO concentrations between reaches; they were not significant ($P > 0.05$) (Table 8). Repeated measures ANOVA was also used to test significance but none was found ($P > 0.10$). Only very small changes in oxygen concentration were measured in artificial redds within reaches over the storm period, and differences were not significant ($P > 0.05$) (Table 9). However, DO below Brown Creek did significantly change ($P = 0.01$) over the storm period although the change was small (0.4 ppm) (Table 9). Mean DO was higher in the overlying surface water than in hatching or emergence baskets during both testing periods (repeated measures ANOVA $P < 0.004$).

Relationships Between Variables

Hatching Stage. Percent of eggs surviving to hatching (STH) was partially inversely related to percent fines by weight and volume ($r = -0.45$ and $P = 0.08$) in the affected reach (Table 10). A slightly stronger significant relationship existed in the control reach ($r = -0.63$ and P

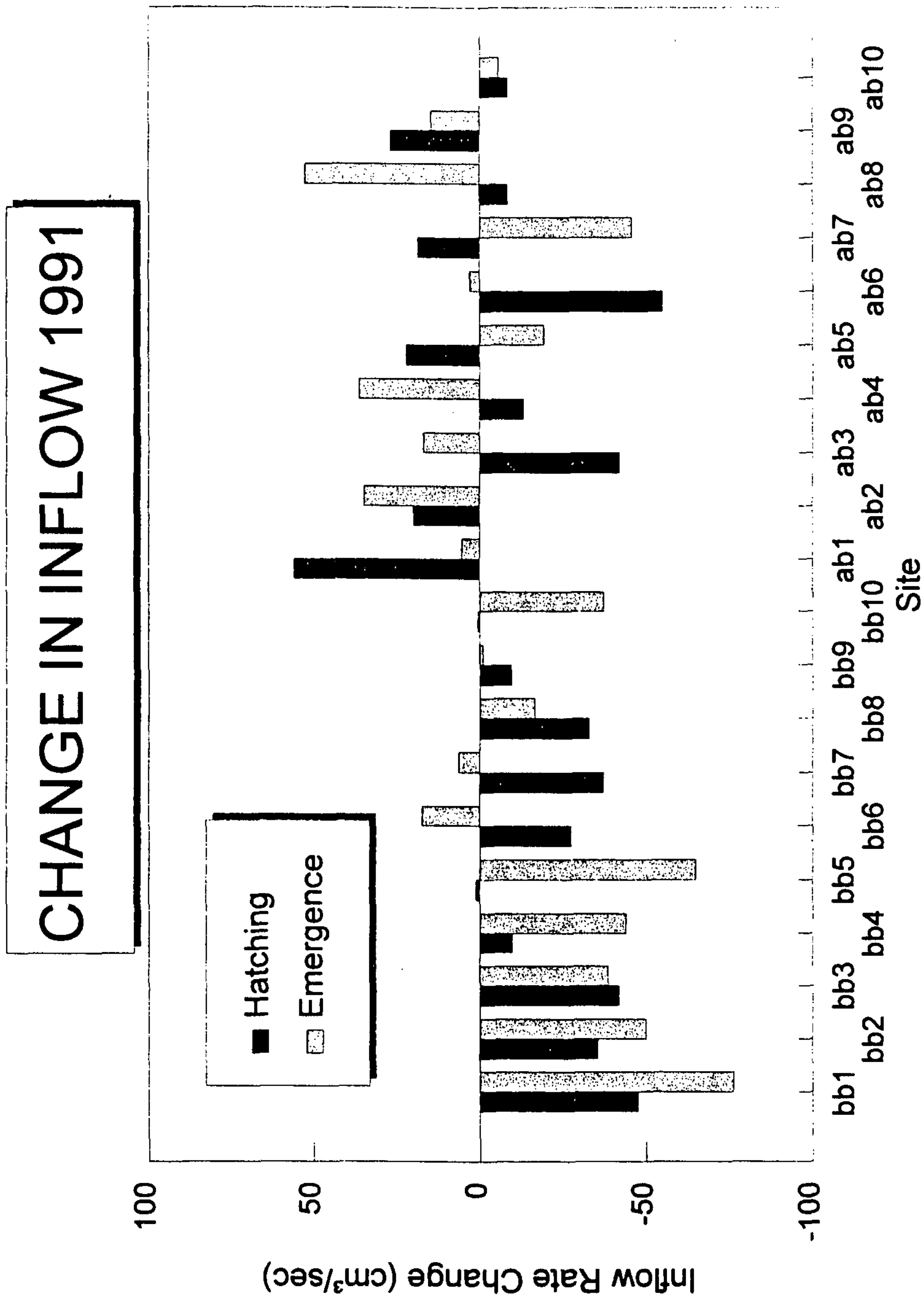

Figure 14. Inflow Rate Change during Incubation of Hatching and Emergence Baskets within Artificial Redds (bb# = Below Brown Creek, ab# = above Brown Creek) on Prairie Creek, CA 1991.

Table 8. Comparison of Affected and Control Reach Mean DO (ppm) Initially and Post-Incubation in Artificial Redds (n = 10) and Adjacent Surface Water of Prairie Creek, 1991.

LOCATION	TEST	AFFECTED REACH Mean (S.E.)	CONTROL REACH Mean (S.E.)	P
INITIAL DISSOLVED OXYGEN				
HATCH BASKETS	T-Test	10.8 (0.1)	10.9 (0.1)	> 0.10
EMERGENT BASKETS	K-W	11.0 (0.1)	11.2 (0.1)	> 0.10
STREAM	T-Test	11.2 (0.1)	11.3 (0.1)	> 0.10
FINAL DISSOLVED OXYGEN				
HATCH BASKETS	K-W	11.0 (1.8)	10.4 (0.2)	> 0.10
EMERGENT BASKETS	K-W	11.3 (0.2)	10.9 (0.2)	> 0.10
STREAM	T-Test	11.6 (0.1)	11.4 (0.2)	> 0.10

Table 9. Comparison of Initial and Final Mean Dissolved Oxygen Concentrations (ppm) in Artificial Redds (n = 10) and Adjacent Surface Water in Affected and Control Reaches of Prairie Creek, 1991.

		INITIAL	FINAL	
LOCATION	TEST	Mean (S.E.)	Mean (S.E.)	P
HATCH BASKETS				
AFFECTED	Wilcoxon's	10.9 (0.1)	11.0 (0.2)	> 0.10
CONTROL	Paired T-Test	10.9 (0.1)	10.4 (0.2)	> 0.10
EMERGENT BASKETS				
AFFECTED	Wilcoxon's	11.0 (0.1)	11.3 (0.2)	> 0.10
CONTROL	Wilcoxon's	11.2 (0.1)	10.9 (0.2)	> 0.10
STREAM BASKETS				
AFFECTED	Paired T-Test	11.2 (0.1)	11.6 (0.1)	0.01
CONTROL	Paired T-Test	11.2 (0.1)	11.4 (0.2)	> 0.10

Table 10. Correlation Coefficients (r) and Significance for Variables Sampled in Hatching Baskets in Artificial Redds in Prairie Creek, 1991.

PARTICLE SIZE (mm)	% SURVIVAL	% ▲ INFLOW	FINAL INFLOW	WORM ABUNDANCE
PRAIRIE CREEK (REACHES POOLED)				
BY WEIGHT				
< 4.75	0.05	0.05	0.11	-0.10
< 1.00	0.09	0.07	0.08	-0.04
< 0.50	0.05	0.01	0.07	0.02
BY VOLUME				
< 4.75	-0.33*	0.14	-0.04	0.37*
< 1.00	-0.37*	0.13	-0.10	0.45**
< 0.50	-0.42**	0.10	-0.12	0.49**
PRAIRIE CREEK (CONTROL REACH)				
BY WEIGHT				
< 4.75	0.45*	0.62**	0.58**	-0.29
< 1.00	0.53*	0.65**	0.63**	-0.32
< 0.50	0.40	0.45*	0.51*	-0.37
BY VOLUME				
< 4.75	-0.49*	0.21	0.11	0.39
< 1.00	-0.63**	0.06	-0.05	0.50*
< 0.50	-0.70**	-0.06	-0.14	0.51*
PRAIRIE CREEK (AFFECTED REACH)				
BY WEIGHT				
< 4.75	-0.39	-0.46*	-0.17	0.00
< 1.00	-0.45*	-0.49*	-0.27	0.11
< 0.5	-0.41	-0.46*	-0.20	0.25
BY VOLUME				
< 4.75	-0.45*	-0.04	-0.27	0.39
< 1.00	-0.44*	0.05	-0.32	0.48*
< 0.50	-0.38	0.15	-0.27	0.54*

* P < 0.10 ** P < 0.05 *** P < 0.01 **** P < 0.001

= 0.05). Strangely, weight of fines tended to show a significant positive correlation in the control reach. A weaker inverse relationship existed (r = -0.37, P = 0.08) between STH and percent fines by volume only, when all site data were pooled. STH was weakly related to percent change in inflow rate (r = 0.38, P = 0.048), but not with ending inflow rate. Percent of organic matter in fines was negatively correlated to STH (r = -0.85, P = 0.004, 68% of variance accounted for) in the control reach, but not the affected reach.

Percent change in inflow rate was negatively correlated to weight of fines in the affected reach; however, in the control reach, both inflow variables were positively correlated to weight of fines (Table 10). No relationship existed when data were pooled. Ranked visual estimates of worms (none, low, medium, or high) were slightly positively correlated to fines, particularly the smallest size classes, (Table 10).

Worm amounts were also correlated to percent organic matter, in the control reach only, (r = 0.52, P = 0.072). Amount of worms and STH were only weakly but negatively correlated (r = -0.31, P = 0.09). However, all baskets containing large amounts of worms and fines > 25% by volume produced no hatched fry. The highest STH (> 20%) resulted when worms were absent and fines were less than 8.0% by volume. No relationship existed between amount of organic matter and upstream direction as predicted.

In multiple stepwise-backwards regression with hatching success as the dependent variable, inflow rate and percent fines were selected in a strong inverse relationship (multiple $r = -0.74$, $P = 0.06$) in the affected reach. Significant correlation was not noted in the control reach. A weak inverse relationship ($r = -0.36$ an $P = 0.08$) existed when all site data were pooled. No relationships between stream variables and DO were investigated because change in DO was small, not significant between reaches and the data were suspect, as discussed above.

Emergence Stage. Strong inverse relationships existed between percent fines by weight and survival to emergence (STE) in the affected reach ($P < 0.01$) (Table 11). Inverse relationships also existed between the same variables by volume, although relationships were less strong and less significant. No relationship was found between STE and either inflow variable. However, a weak inverse relationship was found between percent fines by weight, and final inflow.

No relationships were found between percent fines and STE, or either inflow variable in the control reach (all sites) in single regression equations. No significant relationships existed between any combinations of the above variables in multiple regression equations either.

Table 11. Correlation Coefficients (r) and Significance Levels (*) for Single Regressions between Percent Fines and Other Variables Measured in Emergence Baskets of Artificial Redds in Prairie Creek, 1991.

PARTICLE SIZE (mm)	% SURVIVAL	% ▲ INFLOW	FINAL INFLOW	WORM WEIGHT
PRAIRIE CREEK (REACHES POOLED)				
BY WEIGHT				
< 4.75	-0.64 ***	-0.57 **	-0.45 *	0.03
< 1.00	-0.68 ***	-0.48 **	-0.31	0.10
< 0.50	-0.72 ****	-0.46 **	-0.24	0.21
BY VOLUME				
< 4.75	-0.51 **	-0.26	-0.14	0.03
< 1.00	-0.47 **	-0.10	0.09	0.15
< 0.50	-0.40 *	-0.01	0.22	0.25
PRAIRIE CREEK (CONTROL REACH))				
BY WEIGHT				
< 4.75	0.03	-0.39	0.03	-0.21
< 1.00	-0.21	-0.23	0.19	-0.02
< 0.50	-0.46	-0.27	0.03	0.33
BY VOLUME				
< 4.75	-0.22	-0.12	0.28	0.21
< 1.00	-0.33	-0.08	0.26	0.38
< 0.50	-0.38	-0.07	0.17	0.56
PRAIRIE CREEK (AFFECTED REACH)				
BY WEIGHT				
< 4.75	-0.87 ***	-0.48	-0.60 *	0.03
< 1.00	-0.86 ***	-0.34	-0.46	0.08
< 0.50	-0.82 ***	-0.27	-0.32	0.15
BY VOLUME				
< 4.75	-0.76 **	-0.19	-0.43	-0.19
< 1.00	-0.60 *	0.17	-0.01	-0.12
< 0.50	-0.35	0.41	0.33	-0.06

* P < 0.10 ** P < 0.05 *** P < 0.01 **** P < 0.001

No significant difference existed in percent fines, and either inflow variable between control sites that were exposed to the largest storm of the year, and control sites that were not exposed ($P > 0.10$, $n = 4,5$, T-test). No significant difference existed between affected sites ($n = 10$) and control sites that were exposed to the storm ($n = 4$), and control sites that were not ($n = 5$) ($P > 0.10$, K-W). When both reaches were pooled, strong inverse relationships existed between percent fines by weight and STE in the affected reach ($P < 0.01$) (Table 11). Inverse relationships also existed between the same variables by volume, although relationships were less strong and less significant.

Slight inverse relationships were found between STE and both inflow variables. Weak inverse relationships were found between percent fines by weight, and final inflow and change in inflow. Adding percent fines < 4.75 mm in a multiple regression between percent change in inflow and STE increased r^2 slightly (approximately 2%) but decreased the adjusted r^2 slightly and the significance level by half ($P = 0.063$).

Adding percent fines by other size classes in a multiple regression between change in inflow and survival, only increased r^2 slightly but reduced the significance level. However, adding percent fines < 1.00 mm by volume to the multiple regression between change in inflow and survival increased r^2 by 21%, increased the adjusted r^2 by

9% and was significant at P = 0.056. Similarly for < 0.50 mm by volume in the same equation, r^2 increased by 34%, adjusted r^2 increased by 29%, and P = 0.115.

No relationships existed between weights of oligochaete worms and STE or inflow. However, the addition of the worm weight variable to any multiple regression significantly improved the relationship. In addition, trends in data (at least in the control reach) indicated that worm numbers increased with fines which decreased STE.

Natural Redds. In natural redds, fines < 4.75 mm by weight were inversely related with number of fry produced in the affected reach (r = -0.60, P = 0.076, n = 7), however, no significant relationships were found for other size classes. No significant relationships were found in either control reaches.

Survival During Incubation

Approximately 5300 eggs (4400 eggs for artificial redds and 900 for estimating handling mortality) were removed from four female coho salmon between January 15 and 19, 1992. Twenty-nine percent, 53%, 63%, and 42% of the eggs from each of the four fish were used for the experiment. Remaining eggs from each female were incubated in hatch troughs at the PCFFA rearing site (Figure 2) to quantify non-fertilization rates.

Survival-to-Hatching. Hatching baskets were removed during the first week of April. Observations made indicated that infiltration of fines appeared less, worm infestation was much reduced, and egg survival appeared higher than that in 1991. However, annual precipitation was also less and baskets were removed prior to the largest storm of the year, on April 17.

After an average of 35 days (+ or - 2 days) or 522 temperature units (+ or - 14 temperature units) fertility rates were determined for each fish used in the experiment. Fertilization rates of the four female coho were 75%, 60%, 18% and 62%. Due to space limitations in rearing alevins at the site, percent viability of eggs was not determined. Percentages of eggs surviving to the eyed stage in control baskets from hatch troughs to determine handling mortality were 92%, 69%, 53% and 87% respectively. These eggs were then allowed to finish incubation in hatch troughs.

Figure 15 depicts temperatures for the two treatment reaches on Prairie Creek and control reach on Lost Man Creek during the study period. Stream temperatures were warm through the incubation period in January and February of 1992 (temperature ranged between 7° and 10°C) (Figure 15) and hatchery personnel experienced severe problems with fungi in hatch troughs.

Hatching baskets were removed between April 1 and April 9. Fertilized eggs were incubated an average of 79 days (1275 degree days) after fertilization. The remaining eggs from each female salmon incubated at the PCFFA site hatched under similar water temperatures. Eggs incubated in control egg baskets appeared to have eyed at the same time (at about 35 days and 522 degree days) when compared to eggs incubated by PCFFA in hatch troughs. The eggs reserved to determine handling mortality actually yielded higher survival rates than those eggs incubated by PCFFA to determine fertility rates. Thus, overall survival rates could not be accurately adjusted for mortality due to handling. Repeated measures ANOVA was used to analyze differences over time and between reaches. Data transformation and other statistical analyses followed as before. Mean percent STH was 35.8 (SE = 8.47) in sites

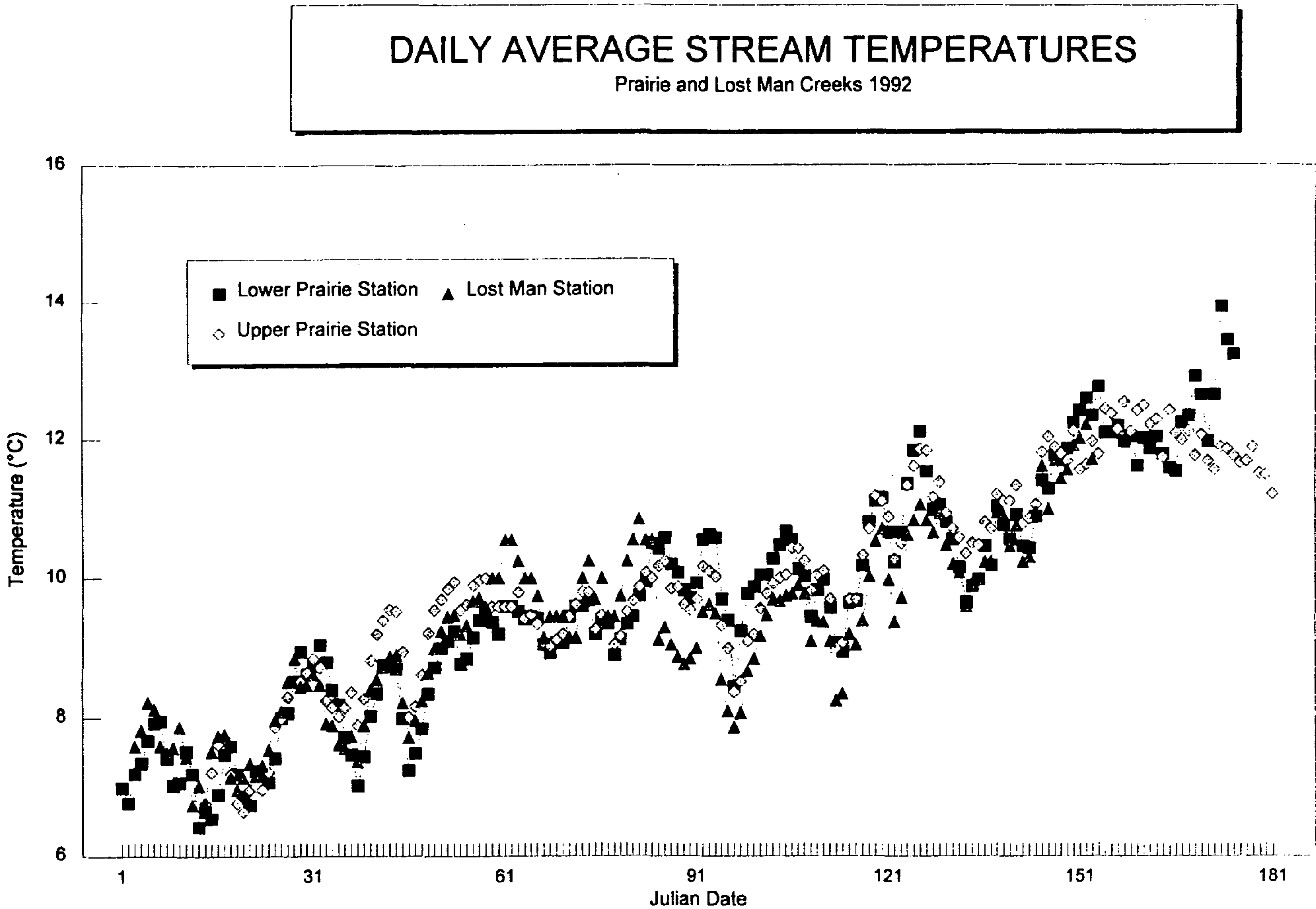

Figure 15. Stream Temperatures in Prairie and Lost Man Creeks, CA between January 1 and June 29, 1992.

located by tributaries, 27.8% (SE = 4.47) in non-tributary sites, and not statistically significant. Thus, data were not analyzed using 'Tributary' as an effect in the overall model. One-way ANOVA detected no significant differences between treatment reaches. Mean percent STH was 32.8 (SE = 4.6) in the affected reach and 23.8% (SE = 4.0) in the control. STH ranged from 2.0% to 76.0% in the affected reach and from 3.0% to 63.0% in the control (Appendix D, E and Figure 16).

Data were also analyzed after adjusting overall survival rates using the coefficients from handling mortality baskets; however, r^2 values were extremely low using this approach, as coefficients were only estimates at best. Because egg survival rates were adjusted for fertility differences, a parent fish grouping factor effect (FISHID) was also investigated. Two-factor multi-variate analysis of variance (MANOVA) to determine differences between main effects (treatment, FISHID and the two-factor interaction) was not possible because not all eggs from each fish were dispersed evenly among treatments; variances could not be calculated for each cell even though attempts were made to equally randomize fish among treatments. One-way ANOVA and Tukey's Least Significant Difference Test, detected significant differences between STH when grouped by FISHID.

To remove the effects due to FISHID, data were analyzed using ANCOVA with FISHID as the covariate (Table 12). No

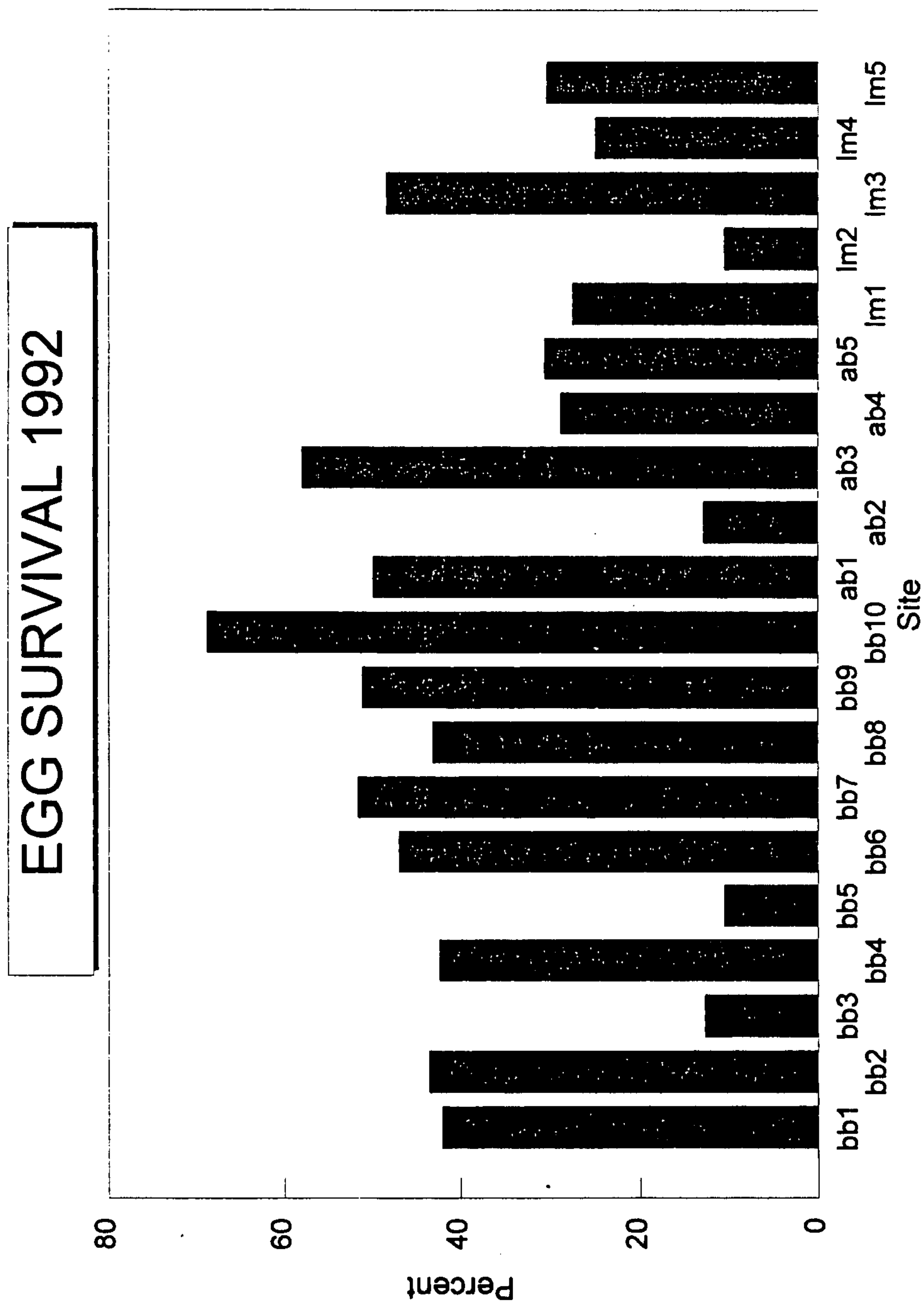

Figure 16. Survival to Hatch within Artificial Redds on Prairie (bb# = Below Brown Creek, ab# = above Brown Creek) and Lost Man (lm#) Creeks, CA 1992.

Table 12. Analysis of Co-variance Tables for Variables Measured in 1991.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG. F
Between Groups	0.416	3	0.139	8.281	0.002
Within Groups	0.234	14	0.017		
Total	0.651	17			

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG. F
Covariates					
FISHID	0.271	1	0.271	11.570	0.004
Main Effects					
TRTMNT	0.027	1	0.027	1.170	0.296
Explained	0.299	2	0.149	6.374	0.010
Residual	0.352	15	0.023		
TOTAL	0.651	17	0.038		

Multiple r^2	0.459
Adjusted r^2	0.678

significant differences were found between treatments, although the covariate was significant (P = 0.004) and the model explained 46% of the variability in survival.

Two baskets (one in each reach) were infested with oligochaete worms (Appendix E). One basket in site number 4 below Big Tree Creek had 22 grams of worms and 100% egg mortality. The adjacent basket within the site had no worms and 87% STH. At site number 22 above Brown Creek, one basket had 11 grams of worms and 15% STH and the adjacent basket had no worms and 45% STH. Mean percent STH in worm infested baskets was 15.7 (n = 2) and in non-infested baskets was 29.7 (SE = 3.2,n = 38). These two worm infested sites (#4 and #22) were removed from data analysis as the data were suspect. However, STH within treatments or when pooled did not appreciably change when worm infested sites were removed from analysis.

Natural Emergence Survival. A total of 94 coho, chinook and steelhead natural redds were counted on Prairie Creek and 183 on Lost Man Creek. Eighteen of these redds were identified and marked to be trapped using fry traps. Date of spawning, fish species, and length (when known) were recorded. Fry traps were placed on the marked redds immediately after fish terminated spawning, and then activated several weeks prior to estimated emergence. Six traps were placed below the confluence of Brown Creek (three below each affected tributary), three placed in the control reach above the confluence, and nine in Lost Man Creek (Figure 5). Redds trapped on Prairie and Lost Man Creeks represented 9.6 and 4.9% of the redds counted during surveys in each stream respectively, in 1992.

Five traps out of nine on Prairie Creek produced fry. Two traps in the affected reach of Prairie Creek produced 3 and 1 fry for a total of 4. All three traps in the control reach on Prairie Creek produced fry (41, 1 and 2). Five traps out of nine on Lost Man Creek produced 2, 41, 27, 276 and 904 fry (Figure 17).

PHYSICAL MEASUREMENTS

Substrate Composition. Mean percent fines (< 1.00 mm) by weight in hatching baskets was 0.58% in the treatment reach and 1.28% in the control. This difference was statistically significant (P = 0.071) (Table 13). The within-subject factor SITE was also significant (P = 0.078). Mean percent fines by volume was 4.32% (SE = 0.79) in the treatment reach and 6.27% (SE = 1.14) in the control. This difference was not statistically significant (P > 0.1) (Table 13). Means and P values for < 4.75 and < 0.50 mm size classes by weight and volume are presented in Table 13 for comparison to other results.

Percent fines ranged between 0.14% and 1.96% by weight and from 1.14% to 16.71% by volume in the affected reach (Appendix F and Figure 18). Percent fines < 1.00 mm ranged

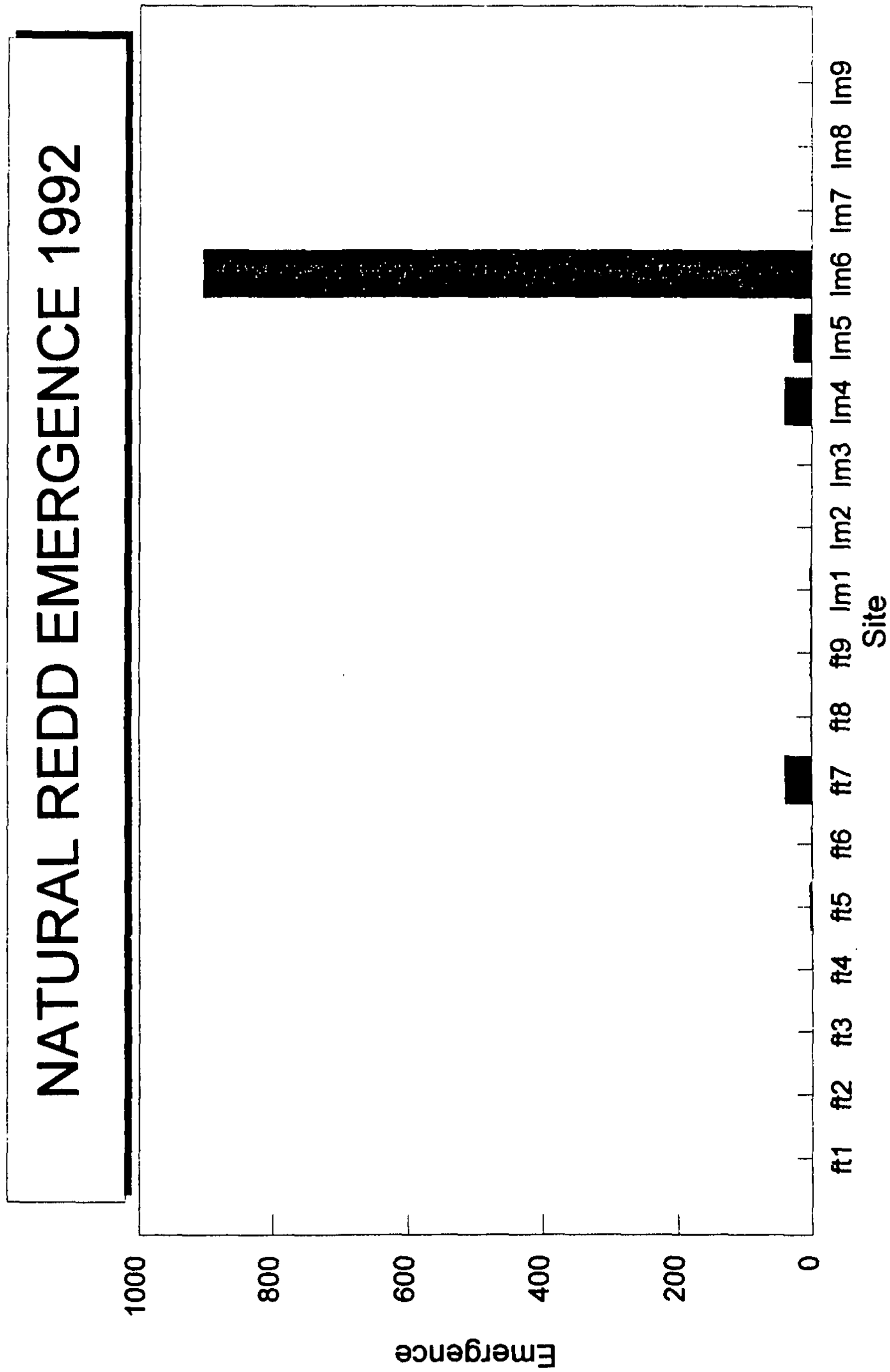

Figure 17. Numbers of Fry Emerging from Natural Redds on Prairie (ft#) and Lost Man (lm#) Creeks, CA 1992.

Table 13. Comparison of Mean Percent Fines in Hatching Baskets (n = 20) of Artificial Redds on the Affected and Control Reaches of Prairie and Lost Man Creeks, 1992.

PARTICLE SIZE (mm)	AFFECTED REACH MEAN	(S.E.)	CONTROL REACH MEAN	(S.E.)	P
BY WEIGHT					
< 4.75	3.08	(0.30)	4.70	(0.56)	0.062
< 1.00	0.58	(0.10)	1.28	(0.24)	0.071
< 0.50	0.42	(0.08)	0.89	(0.20)	0.110
BY VOLUME					
< 4.75	6.87	(0.82)	9.59	(1.29)	> 0.10
< 1.00	4.32	(0.79)	6.27	(1.14)	> 0.10
< 0.50	4.15	(0.78)	5.90	(1.11)	> 0.10

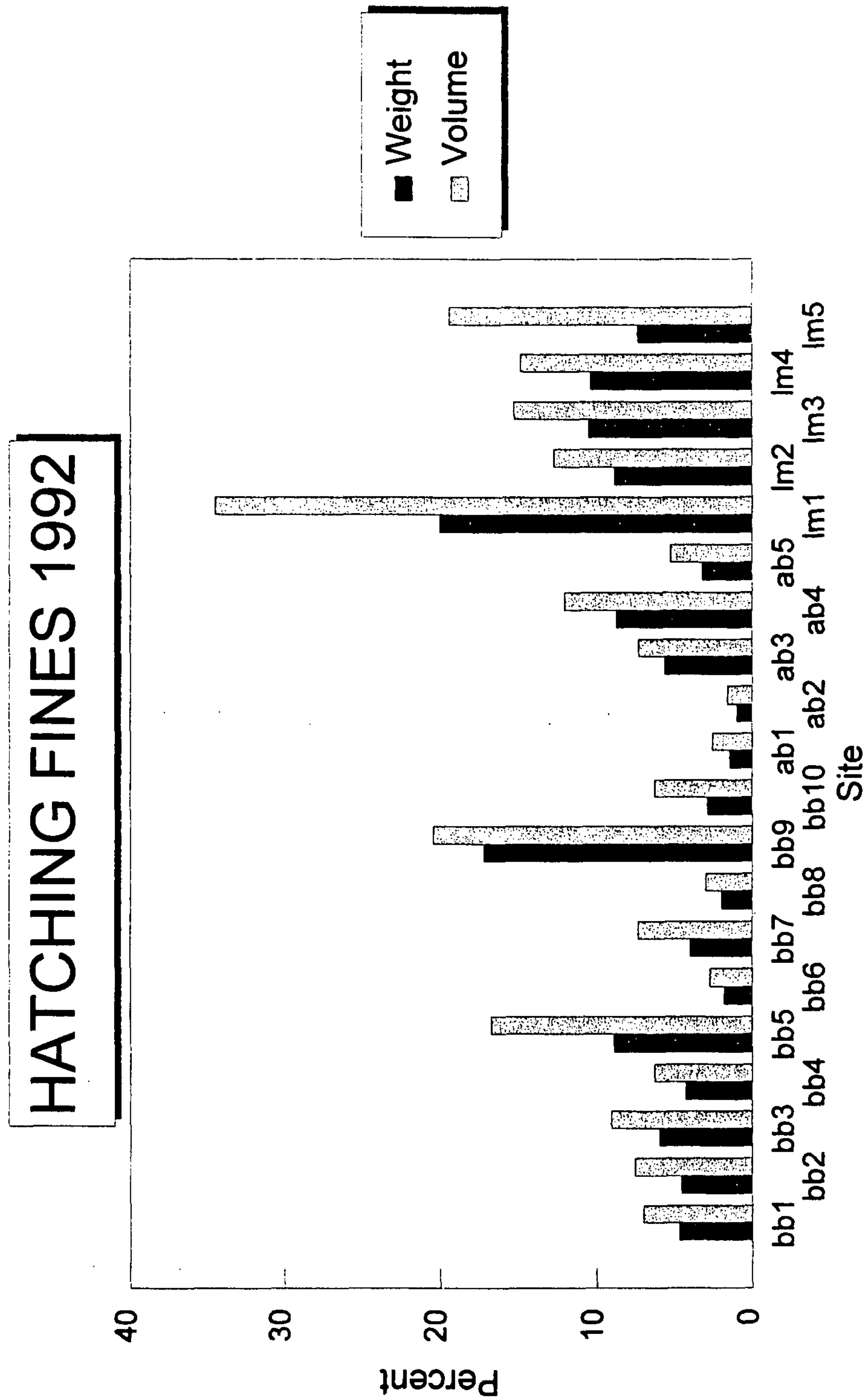

Figure 18. Percent Fines (< 1 mm) by Weight and Volume within Artificial Redds on Prairie (bb# = below Brown Creek, ab# = Above Brown Creek) and Lost Man (lm#) Creeks, CA 1992.

between 0.10% to 3.93% by weight and from 0.72% to 18.40% by volume in the control reach.

Substrate samples were not collected in natural redds since data were thought to be suspect, due to fry traps aggrading fines artificially. Most fines observed appeared solely on the surface and were deposited due to the decrease in stream velocities as a result of the trap.

Permeability and Dissolved Oxygen. There were no statistical differences in mean initial inflow rates between affected and control reach baskets. There were no statistical differences in mean final inflow rates between affected and control reach baskets either. In the affected reach, initial (January) mean inflow rate was 107.1 cm^3/sec, final (March) was 96.5 cm^3/sec, and differences (dummy variable TIME) were significant ($P = 0.041$, $n = 10$) (Table 14 and Figure 19). A significant within-subject effect (TEST WITHIN SITE) was detected as well ($P = 0.001$). The interaction between variables was not significant. Differences tested without the within-subject effect (TEST WITHIN SITE) between left and right baskets regardless of time (dummy variable 'SITE') were also significant ($P = 0.035$, $n = 20$).

In the control reach, initial mean inflow rate was 111.1 cm^3/sec, final rate was 90.9 cm^3/sec, and differences were significant ($P = 0.001$, $n = 10$). The within-subject

Table 14. Comparison of Mean Inflow Rates (cm^3/sec) in Artificial Redds (n = 10) in the Affected and Control Reaches using Repeated Measures ANOVA, 1992.

	Affected Reach		Control Reach	
	Mean	(S.E.)	Mean	(S.E.)
Initial	107.1	(3.6)	111.1	(13.9)
Final	96.5	(2.9)	90.9	(2.9)
Change (%)	-9.2	(3.4)	-17.5	(3.2)
P	< 0.05		< 0.05	

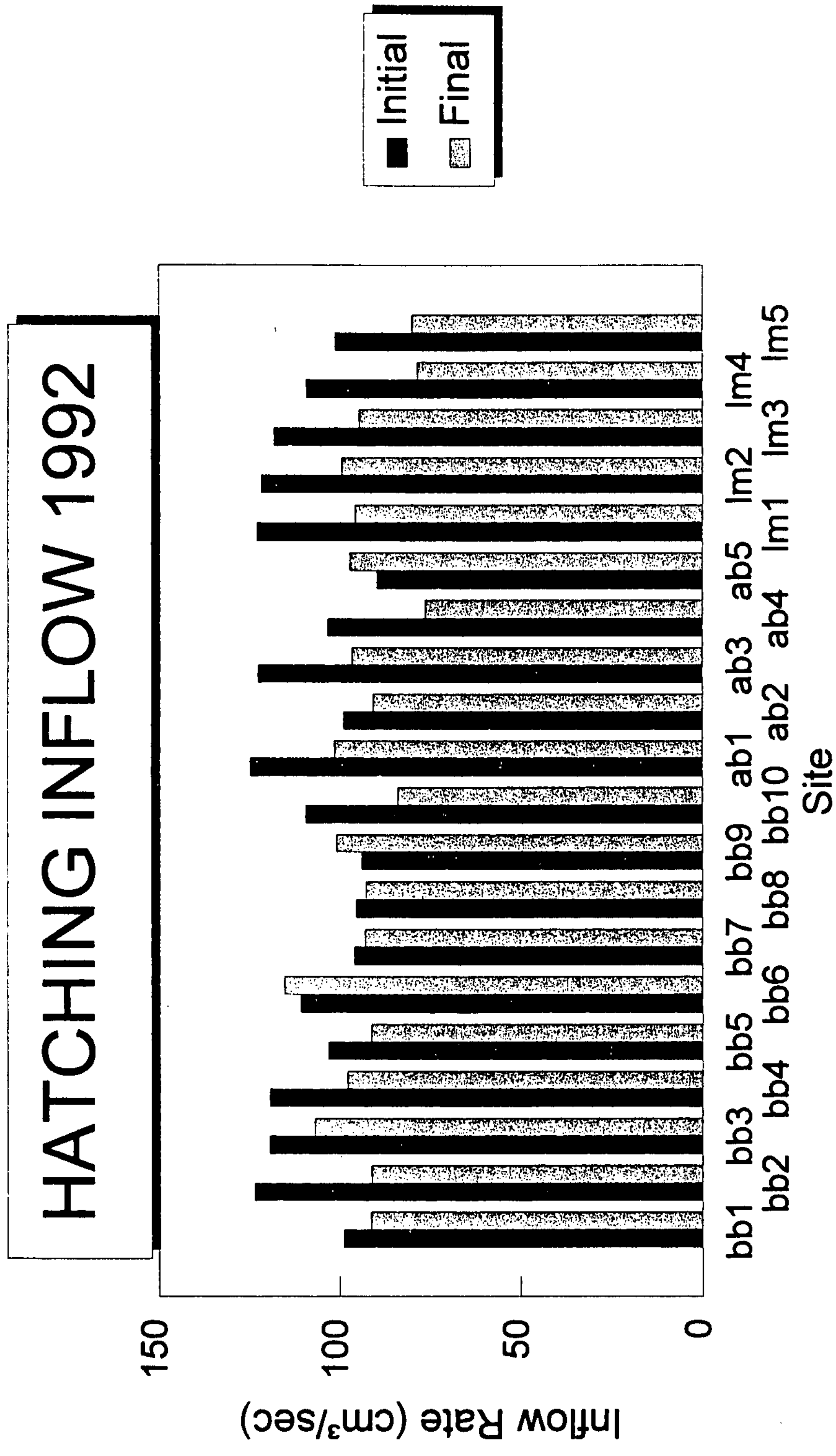

Figure 19. Comparison of Inflow Rates over the Incubation Period of Artificial Redds, Prairie (bb# = below Brown Creek, ab# = Above Brown Creek) and Lost Man (lm#) Creeks, CA 1992.

effect was not significant, however, a significant interaction between variables was detected (P = < 0.001).

Differences without the within-subject effect (TEST WITHIN SITE) between left and right baskets regardless of time (dummy variable 'SITE') were significant (P = 0.001, n = 10). A significant interaction TIME BY SITE was also detected (P = 0.016). Mean change in inflow rates over the incubation period were -9.2% in the affected reach, -17.5% in the control reach, and were not statistically different (Figure 20). Raw data are presented in (Appendices D and E).

No differences were measured between initial DO concentrations and adjacent surface water. However, significant differences were found between final DO concentrations and adjacent surface water for both reaches, although differences were small (Table 15). Significant changes in concentration were measured in artificial redds within reaches over the storm period as well, although differences were also small (P < 0.05) (Table 16).

DO was compared between treatments both prior to and after each incubation period using repeated measures ANOVA. Prior to incubation, mean DO in the affected reach was 12.0 ppm (SE = 0.1) and 12.3 ppm (SE = 0.2) in the control (Table 15 and Appendix G). Post incubation, mean DO in the affected reach was 10.7 ppm (SE = 0.1) and 10.6 ppm (SE = 0.1) in the control. No significant differences were found between treatments, or between sites within treatments prior to or

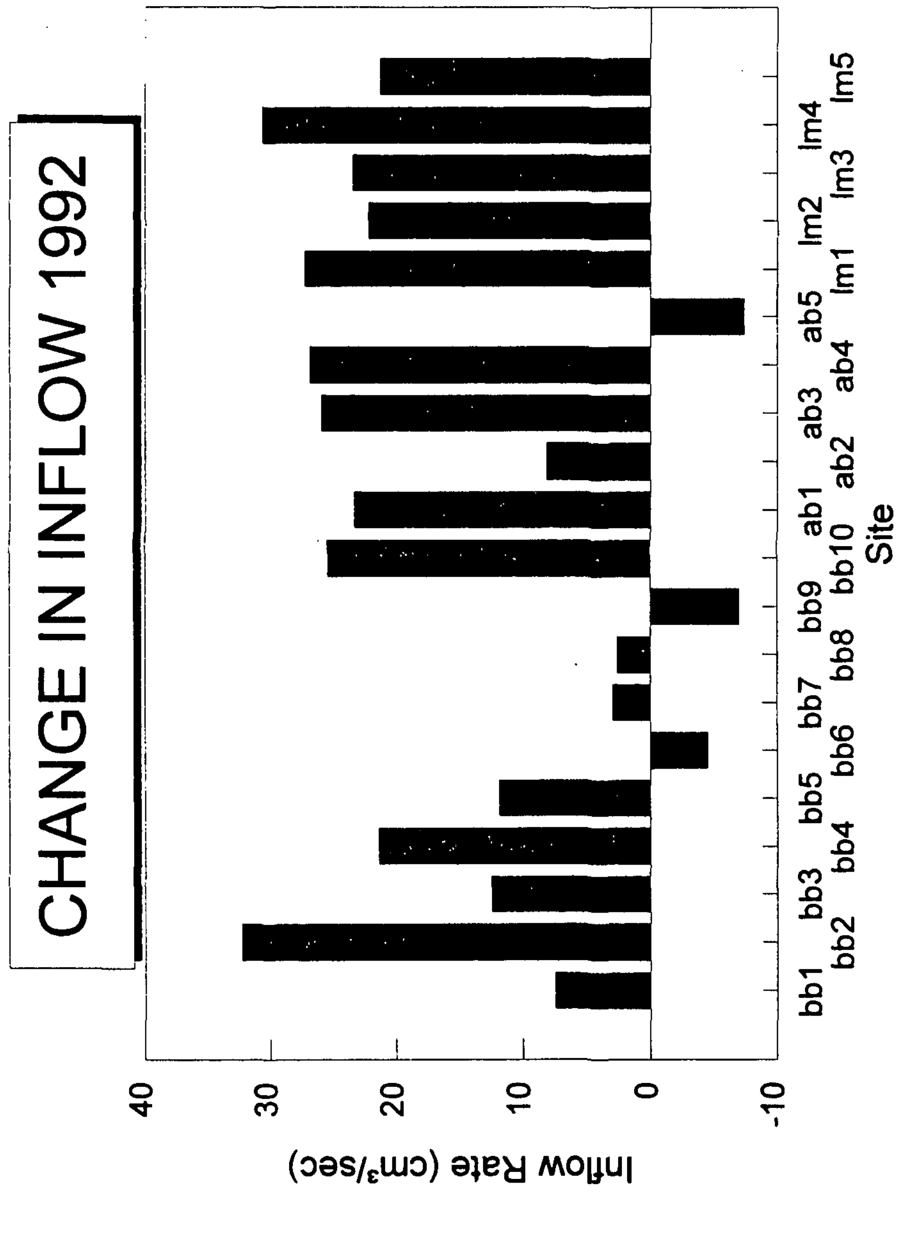

Figure 20. Inflow Rate Change during Incubation of Artificial Redds on Prairie (bb# = Below Brown Creek, ab# = Above Brown Creek) and Lost Man (lm#) Creeks, CA 1992.

Table 15. Affected and Control Reach Mean Dissolved Oxygen Concentrations (ppm), Initially and Post-Incubation in Artificial Redds (n = 10) and Adjacent Surface Water 1992.

	REDD		SURFACE		
LOCATION	MEAN	(S.E.)	MEAN	(S.E.)	P
INITIAL DISSOLVED OXYGEN					
AFFECTED	12.0	(0.1)	11.9	(0.1)	> 0.10
CONTROL	12.3	(0.2)	12.4	(0.3	> 0.10
FINAL DISSOLVED OXYGEN					
AFFECTED	10.7	(0.1)	11.2	(0.1)	< 0.001
CONTROL	10.6	(0.1)	11.5	(0.1)	< 0.001

Table 16. Initial and Final Mean Dissolved Oxygen Concentrations (ppm) in Affected and Control Reach Artificial Redds 1992.

	REDD		SURFACE		
TIME	MEAN	(S.E.)	MEAN	(S.E.)	P
INITIAL	12.0	(0.1)	10.7	(0.1)	< 0.001
FINAL	12.3	(0.2)	10.6	(0.1)	< 0.001

	INITIAL		FINAL		
REACH	MEAN	(S.E.)	MEAN	(S.E.)	P
AFFECTED	12.0	(0.1)	12.3	(0.2)	> 0.10
CONTROL	10.7	(0.1)	10.6	(0.1)	> 0.10

post incubation. The interaction term between site and treatment was not significant for either test.

Relationships Between Variables

Six different regression models were run (corresponding to three different size classes of fines, each represented by a weight or volume measurement) (Table 17). Separate models were run for each subset rather than specifying all possible variables at once because: 1) severe multi-collinearity would exist between each size class of fines; 2) I wished to investigate each two-variable interaction; and 3) r^2 tends to increase artificially with increasing numbers of variables. A general rule suggests that there should be six to ten cases for every variable in the pool (Neter et al. 1990). In my study there were 4 variables for 36 cases (corresponding to nine cases for every variable).

In the affected reach, STH was strongly and inversely correlated with percent fines by weight, particularly with larger size classes, but less strongly by volume (Table 17). In the control reach, no relationship existed between percent fines and STH. STH was barely negatively correlated with percent fines by weight and not at all with volume when data were pooled. Percent fines and final inflow rate were barely negatively correlated when data were pooled only. No relationship existed between percent fines and change in inflow rate.

Table 17. Correlation Coefficients (r) and Significance Levels (*) for Single Regressions between Percent Fines and Other Variables Measured in Artificial Redds, 1992.

	% SURVIVAL	FINAL INFLOW RATE
PRAIRIE CREEK (REACHES POOLED)		
BY WEIGHT		
< 4.75	-0.37 **	-0.44 ***
< 1.00	-0.32 **	-0.36 **
< 0.50	-0.33 **	-0.29 **
BY VOLUME		
< 4.75	-0.25 **	-0.41 ***
< 1.00	-0.19	-0.32 **
< 0.50	-0.18	-0.30 **
PRAIRIE AND LOST MAN CREEKS (CONTROL REACHES)		
BY WEIGHT		
< 4.75	0.03	-0.21
< 1.00	-0.21	-0.02
< 0.50	-0.46	0.33
BY VOLUME		
< 4.75	-0.22	-0.21
< 1.00	-0.33	0.38
< 0.50	-0.38	0.56
PRAIRIE CREEK (AFFECTED REACH)		
BY WEIGHT		
< 4.75	-0.87 ***	0.03
< 1.00	-0.86 ***	0.08
< 0.50	-0.82 ***	0.15
BY VOLUME		
< 4.75	-0.76 **	-0.19
< 1.00	-0.60 *	-0.12
< 0.50	-0.35	-0.06

* P < 0.10 ** P < 0.05 *** P < 0.01 **** P < 0.001

Since no significant differences were found in any consistent or reliable pattern to indicate that distinct differences existed between treatments for any of the measured variables, multiple regressions were run on all data pooled (n = 36) to detect relationships between the physical variables measured and survival. Four data points were removed due to presence of oligochaete worms.

Relationships were first investigated between all variables to detect multi-collinearity. Relationships between survival, and the continuous variables (percent fines and inflow rate) and the categorical variable (FISHID) were determined using multiple regression analysis with SPSS statistical software.

Table 18 presents an analysis of variance table and regression statistics for the best model. The stepwise-backwards procedure was specified again which was useful when running many different equations with different combinations of variables. Three variables were included: ATW4.75 (percent fines), AVGFINAL (final inflow rate), ATFERT (fertilization rate of fish) with ATLIVE (uncorrected STH) as the dependent variable.

R^2 with all three variables in the model was 0.56 (adjusted r^2 = 0.52). This three variable model was statistically significant (P = < 0.001). Removing AVGFINAL reduced r^2 only slightly (by -0.00073) but increased

Table 18. Analysis of Variance Tables for Stepwise-Backwards Regression Model.

VARIABLES ENTERED ON STEP NUMBER:
1. ATFERT
2. ATW4.75
3. AVGFINAL

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG. F
REGRESSION	0.984	3	0.328	13.98	0.0001
RESIDUAL	0.750	32	0.023		
TOTAL	1.734	35			
r^2	0.5674				
MULTIPLE r^2	0.7532				
ADJUSTED r^2	0.5268				

VARIABLES REMOVED ON STEP NUMBER:
4. AVGFINAL

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG. F
REGRESSION	0.9824	2	0.4912	21.57	0.0001
RESIDUAL	0.7514	33	0.0228		
TOTAL	1.7338	35			
r^2	0.5666				
MULTIPLE r^2	0.7528				
ADJUSTED r^2	0.5404				

adjusted r^2 by 0.014. The three variable model was statistically significant (adjusted $r^2 = 0.54$, $P < 0.001$). Removing the fish effect (variable ATFERT) from the final model reduced r^2 by 0.34 ($P = 0.026$).

The two variable model, percent fines classified as < 4.75 mm by weight (variable ATW4.75), and fish (variable ATFERT), explained the variability in percent fines the best. Diagnostic plots showed that data met assumptions necessary for analysis.

Plots demonstrated the relationship between increasing fines and decreasing inflow rate (indicating multi-collinearity). The fact that r^2 decreased, but adjusted r^2 increased when AVGFINAL was removed in the above analysis, further strengthened the assumption that fines and final permeability were related, although weakly. Plots of the residuals versus the interaction term between inflow and fines, showed error distribution appeared random about zero and no systematic tendencies were apparent, thus error variance appeared constant. Although some multi-collinearity was apparent between percent fines, inflow and STH, the interaction term may be inappropriate and non-significant as the above analysis implied.

Plots of the residuals against other independent variables enabled further analysis into the appropriateness of the regression function. In a plot of the residuals against ATFERT, although error variances were not completely equally distributed about zero for each fish, no systematic pattern was apparent overall.

In the scatterplot of inflow with percent fines, error variance appeared fairly constant although there was a slight tendency for variability in permeability to decrease with increasing fines. In the plot of the residuals against percent fines, error variance also appeared nearly constant, although there was a slight tendency for error variance to decrease with increasing percentages of fines. These relationships, if more severe, would tend to violate the assumptions of constant error variance. In addition, not enough data may be available at larger values of percent fines to demonstrate any systematic tendencies in the data set.

The normal probability plot of the expected values versus the observed, demonstrated that the error distribution approximated normality (i.e., the plot did not depart substantially from linearity). Thus, the assumption of normality of error terms was met for the regression function. For explaining survival however, the parent fish variable alone explains 38% of the variability, and percent fines alone explains only 14% of the variability. Together, the two variables explained 54% of the variability in survival (Table 18).

DISCUSSION

1991

Survival-to-Hatching

During storm events, fine sediment transport in suspended load or as bedload accumulates in the gravel framework of the streambed. This occurs as fine bedload material sifts downward through interstitial pathways and as a portion of the suspended load settles out from the intragravel flow of turbid water (RNP 1991a). Increasing content of fine sediment has been shown to decrease fry survival (Chapman 1988). Fine sediment accumulation near the gravel surface, may also cause a sealing layer to form (Diplas and Parker 1991: Lisle 1989) which could block emergence of fry from the streambed, causing mortality.

My experiment was set up to measure the quantity and effects of fine sediment within the gravel column. Results indicated that overall hatching survival was low, both in the affected and control reaches. Hatching baskets were placed in artificial redds in January just prior to the largest storm of the year. Fifty six percent of the fines transported in wateryear (WY) 90-91 are attributed to this storm (RNP 1991a). The second largest storm occurred in March when 29% of the year's fines were transported. These two storms transported 85% of the total sediment transported during WY 90-91 (RNP 1991a). Most dead eggs recovered from hatching baskets appeared to have died shortly after reaching the eyed stage, which indicated that mortality due to handling was low. The increase in percent fines during the incubation period from the storms probably caused the impacts in hatching baskets.

Studies have shown percent survival to hatching under natural conditions is high, 60 to 90% by Hobbs (1940), 54% by Carl (1940), 66% by Shapavalov and Berrian (1940), and 77% by White (1930). STH during my experiments was considerably lower below Brown Creek (< 1%) than STH in the 1990 RNP study (71%) (RNP 1989). However, sample size for the 1990 study was small (n = 2), eggs were incubated under different flow conditions, eyed steelhead eggs were tested, and baskets were removed at hatching.

Although the percentage of fine sediment did not differ between the two reaches, relationships between other factors which have been shown to cause mortality in salmonid embryos (decreased permeability and masses of oligochaete worms) were analyzed. Increasing content of fine sediment has been shown to decrease permeability of streambed gravel (Chapman 1988). During egg incubation, the rate of water seepage usually declines, from the original cleansed condition of the redd, as fines transported downstream by flow events re-infiltrate gravel (Gangmark and Bakkala 1958). Turbulence of water over redds also tends to remove fines and improve seepage, resulting in a fluctuating pattern of seepage throughout the incubation period (McDonald and Shepard 1955).

While these storm processes may decrease permeability deep in the gravel, development of a sealing layer of fines near the gravel surface also tends to inhibit downwelling of surface water into the streambed, which is necessary to maintain intragravel flow rates and thus adequate dissolved oxygen levels (Vaux 1968). As permeability decreases, so does the rate of intragravel flow. Salmonid eggs incubating in the streambed depend on sufficient intragravel water flow for supplying DO and removing metabolic wastes.

Although significant relationships were not found between egg survival and inflow rate, and inflow rate and percent fines, trends were apparent. The lowest survival coincided with the largest decreases in inflow and the highest survival occurred with actual increases in inflow (Figures 7 and 15). A trend was also apparent in decreasing inflow in a downstream direction.

Even though decreases in inflow rates were observed, only very small changes in dissolved oxygen rates were measured in artificial redds. Dissolved oxygen concentrations in any of the redds never dropped below 9.6 ppm, and the range for most redds was between 10 and 12 ppm. These levels were only slightly lower than adjacent surface water levels, and are well within the tolerance of incubating salmonid eggs (CDFG 1980). Measured differences in DO can probably be attributed to differences in water temperature (thus differences in saturation potential), or to variation in calibration of the instrument.

The stronger relationship between change in inflow rate, percent fines and hatching success below Brown Creek, versus over all sites, and lack of relationship above Brown Creek, suggested that other factors were affecting results. Mean percent fines < 1.00 mm in baskets in the 1990 RNP study was 2.6% and ranged from 1.2 to 2.6% by volume. Mean percent fines in 1991 baskets was 11.82% by volume and ranged from 3.9% to 21.7% (an increase of over 9%).

The 55% oligochaete worm infestation rate represented a 35% increase over the 1990 RNP study. It was not clear as to what specific effects these worms have on survival, although Briggs (1953) found that egg mortality positively correlated with degree of infestation (thus the name ichthyophagous i.e.,"fish eaters"). Other literature on these worms is lacking. Briggs' information agreed with the trends in my results. Mean survival in worm-infested redds was 1.98% while mean survival in non worm-infested redds was 8.79%. Further, when worm-infested redds were excluded from analysis, mean survival in redds below Brown Creek and above Brown Creek increased by 26% and 28% respectively.

Although significant relationships could not be found between number of worms and egg survival, finding worms in baskets did not necessarily preclude mortality to eggs. In none of the many gravel samples taken in 1991 and 1992 were worms found in large masses except in egg baskets or in natural redds. Worms may be drawn to the egg baskets by organic matter. More research is needed to determine if and how worms affect eggs, and how long they stay in the redd.

The relationship between number of worms and percentages of fines among treatment reaches can be explained biologically. Seventy percent of all redds below Brown Creek were infested with oligochaete worms and worms occurred in 'clean' and in 'dirty' redds. Only 40% of redds upstream of Brown Creek were infested and worms occurred only in 'dirty' redds. Worms were more distributed below Brown Creek then above Brown Creek. Further, when worms were present in high abundance and fines were greater than 25% there was no hatching survival above or below Brown Creek. When no worms were present and fines were less than 16% there was relatively good survival.

If worms had been absent from the study I may have found a larger difference in percent survival between the two reaches. Mean percent fines in 1991 baskets was 11.5% versus 2.6% in 1990. Worm distribution may have increased due to the larger percentage of fines by WY 90-91.

Fines appeared the factor limiting survival below Brown Creek (complicated by worms) whereas above Brown Creek, reduced survival appeared to be attributed to worms (complicated by fines). The darker color of fines above Brown Creek suggested that the majority of the fine fraction here was inherent to the geology, (however an unknown percentage of fines was introduced by the Bypass via Ten Tapo Creek). This fine fraction also appeared more flocculated than fines below, possibly representing higher organic matter content. The more golden color of fines below Brown Creek is not characteristic of the geology however, and this sediment appeared to be more of a clay type particle that would inhibit intergravel flow and oxygen levels.

Although there was more organic matter in infiltration bags in the control versus the affected reaches, the small difference did not account for the lack of differences in particle size distribution curves between reaches. This can be surmised from the lack of a significant difference in percent fines between reaches after removing the organic matter component. The results were consistent with the 'river continuum principle' of Vannote et al. (1980), which theorizes that increasing amounts of organic matter are found in an upstream direction, where canopy and thus leaf drop are higher.

The disparity in abundance estimates of worms between hatching basket and emergent baskets can probably be attributed to sample size. However, this result was inconsistent with the hypothesis that numbers of worms increase with increases in sediment, as by far most worms were found in hatching baskets. Results of T-tests discussed earlier with worm abundance was consistent with the expected hypothesis. However in absence of any significant relationships no conclusions could be made. Overall my findings indicate:

1) mortality to eggs occurred prior to the hatching stage due to decreased gravel permeability;

2) if eggs survived to hatch, they generally survived to emerge; and

3) mortality to eggs could be traced, at least partially, to fine infiltration, and indirectly to decreased permeability and worm infestation.

Survival-to-Emergence

Although STE was significantly different between the affected and control reaches, most mortality probably occurred during the hatching phase. Therefore STE would have been higher had eggs not undergone impacts incurred during the hatching phase. When STH was compared to STE within individual sites this was apparent (Figures 8 and 9). The decreased mean survival observed for embryos which underwent the largest storm of the year compared to embryos which did not (4% compared to 38%) strengthened this supposition.

Timing of initial and peak emergence was approximately the same for both reaches (the affected reach fry were several days behind) and fry from both reaches generally appeared to be in healthy condition. However, fry incubated in hatch troughs began emerging 33 days earlier, indicating that emergence in the stream was markedly delayed. This was significant in that delayed emergence has been shown to cause indirect mortalities because fry are smaller and weaker and therefore less likely to successfully compete for food upon emergence.

Results also showed that most of the fines occurred at the bottom level of the strata, the level of the egg pocket. However, no fry were found entrapped within gravel at the time of basket removal. This negated my hypothesis that fines would form a 'sealing layer' and affect emergence survival.

Data indicated that abundance weights of worms increased with fines, that the percentage of fines and abundance of worms were higher in sites that underwent the largest storm, and that egg survival was significantly less in sites that underwent the largest storm. Although the relationship was indirect, it indicated worms may have had some affect on survival. These trends were similar to results found in control reach hatching baskets, although results for hatching baskets were stronger (r^2 = 0.64, P = 0.005).

Of all hatching and emergence baskets, 61% (24 of 39) were infested with worms. When emergent baskets were removed, worms appeared much more dispersed among the baskets, in comparison to hatching baskets, where worms were mainly found clustered around the masses of eggs within the egg pocket. Although individual emergent baskets were generally less infested than hatching baskets, and worms were less clustered in emergence baskets, a larger percentage of emergence baskets were infested. The worms may have eaten all the egg material and then departed prior to basket removal. These are general observations however, because worm abundance in hatching and emergent baskets were not quantified in the same way.

In contrast to results of hatching basket analysis, significant differences were found in percent fines between reaches, although the differences were not large. This indicated the affected reach was slightly more impacted with fines than the control reach.

Relationships between emergent basket variables were also clearer than for hatching baskets. Better relationships existed between the larger size fractions and STE (Table 10). The r^2 value decreased and the significance level increased with decreasing particle size for both weight and volume. This was opposite for hatching survival, where a smaller size fraction by volume was the better explanatory variable.

The disparity between results of weight and volume analyses was probably an artifact of methods used to transform data. However, the disparity between hatching and emergence survival explanatory variables could be at least partly explained in reviewing how the physical properties of particles affect stream systems and organisms that live in them. Mortality to emerging fry is more likely to occur due to larger particles entrapping fry, decreasing movement of fry within gravel, or causing abrasion. Whereas mortality to eggs prior to hatching, would be more likely to occur due to smaller particles which have a higher propensity to reduce oxygen by blocking water flow.

The significant multiple regression equations between percent fines at < 1.00 and < 0.50 mm, and change in inflow and STE, substantiate the assertion that egg survival is inversely related to fines, and that an increase in fines causes a larger negative change (decrease) in inflow. This was particularly revealing in that no significant relationship was evident in single regression equations with STE and each independent variable alone. Thus, although no fry were found entrapped in the gravel, infiltration of fines appeared to have had at least a partial effect on STE.

As indicated above, fines appeared to have indirectly influenced survival through reducing permeability of gravel, and delaying emergence of fry. Since no differences were found in percent fines between control sites that underwent the largest storm of the year and those control sites that did not, relationships between predicting variables (fines and inflow) and the response variable (STE) were first analyzed without separating the samples. However, no significant relationships existed.

I would have predicted that with some control sites exhibiting low survival, low permeability and high fines, a relationship similar to what was found in the affected reach occurred, i.e., that these factors decreased STE. However, variables such as geometric mean diameter, stream gradient, and presence of worms were highly variable in the control reach and may have confounded any direct relationships.

Although no significant differences existed between control reach emergent baskets that underwent the largest storm and those that did not, trends suggested that emergent baskets encountered different stream conditions during the incubation period than hatching baskets did. Differences in survival within the same redd between hatching and emergent baskets could be explained by the physical location of baskets within redds. Baskets within redds were always in the same location for all sites. The emergent basket was always just downstream of the pot, and may have allowed proportionally higher fine infiltration into emergent baskets. The configuration of the pot, which enhances downwelling, might have allowed increased survival through increased oxygen flow in emergent baskets in relation to hatching baskets which were further downstream. Future research would clarify this effect.

As discussed above, initially no significant difference was detected in STE between the affected and control reaches over all sites. However, when the four control baskets not subjected to the largest storm were removed from analysis, STE was significantly different; 23.5% in the affected vs. 38.6% in the control reach ($P = 0.041$, K-W). In an effort to better understand this confounding relationship, regressions were developed taking into account temporal differences between the control sites.

When sites that did not undergo the largest storm were removed from regression analysis, strong inverse relationships were found between the larger size fractions and STE, and r^2 values decreased and significance levels increased with decreasing particle size (Table 11). The observation that percentage by volume acted as a better predictor may be an artifact of data transformation, or may be due to the intrinsic properties associated between stream particles and flow dynamics, as discussed before.

No significant relationships were found in regressions of fines and STE between those sites that underwent the largest storm. No significant relationship was found between inflow and survival either. However, very strong inverse relationships were found between fines and final inflow (r = 0.99, P = 0.01) which indicated fines decreased permeability. However, the addition of inflow in a multiple regression between fines and STE did not significantly change any r^2 ratio or significance level. Careful interpretation of these results must be made in that sample sizes are small (n = 5,4), increasing the chance of a Type Two error (rejecting a true null hypothesis).

Natural Emergence Survival

In natural populations, most of the mortality to juveniles occurs between the fry emergence and smolt stages (Shapavalov and Taft 1954) and survival rates less than 2% are common. Any losses in percent survival that occur pre-smolting can have serious effects upon population dynamics. Fry traps were placed on marked redds several weeks before fry were expected to emerge, however, it is not known whether all redds were 'true' redds (i.e., fish actually deposited eggs) or whether all eggs were fertilized. Briggs (1953) estimated a 30% false redd rate when digging up redds on Prairie Creek.

Fry held at the PCFFA rearing site began emerging after approximately 62 days, (936 degree days). On Prairie Creek, fry emergence from fry trap #5 started after 95 days (1604 degree days), a difference of 71% or 668 degree days. Natural emergence was markedly delayed. However, these results were from one redd, the only redd out of nine that exhibited emergence. Large numbers of young of the year fry were not seen in Prairie Creek by stream surveyors until approximately this same time indicating that other redds exhibited similar delays.

Fry emergence on Lost Man Creek peaked 28 days earlier than on Prairie Creek. Perhaps emergence time was delayed due to differences in temperatures. Significantly, all three traps on Lost Man Creek exhibited emergence.

In 1990, 69% of the spawning occurred below the Boyes Creek confluence, 27% in the reach between Boyes and Brown Creek confluences and only 4% above the Brown Creek confluence. Considering that STH and STE were both zero percent in artificial redds below Boyes Creek, fry production by natural spawners was probably very low.

The percentage of fines < 1.00 mm in fry traps was considerably greater and more variable than in emergence baskets. However, temporal differences existed between redd construction by natural spawners, thus redds underwent different storms. Although the fry traps were in the stream for only a brief time during the incubation period, several traps accumulated fines above natural conditions. Studies by researchers in Montana using fry traps over brown trout redds showed significantly higher concentrations of fine sediments in gravel samples collected from beneath the traps than outside them (Reiser and Olson 1992). Olson (1996) also found such high increases in fine sediment under emergent fry traps in a study on the North Fork Salmon River, California, that the traps had to be removed periodically to be cleaned. In my study, redds were not covered by fry traps during the critical period of incubation (from egg to hatching), thus elevated fines could not have affected STH results and may not have affected STE significantly.

Sampling methods used to collect gravel differed between natural redds (McNeil's) and artificial redds (infiltration bags). McNeil samples were found to sample fine sediment more readily than freeze cores in a comparison of the two methods (Meyer et al. 1991), although no test comparisons have been made between McNeil samples and infiltration bags. Fines were observed flushing downstream during the process of removing infiltration bags, thus fine sediment data from artificial redds represented a minimum measure. Mean fine sediment percentages in artificial redds was probably under-estimated while percentages in natural redds was over-estimated.

In general, results and trends in natural redds followed those of artificial redds. Incubation times were similar, redds went through similar storms, and both types of redds were sampled in similar reaches and in similar numbers. Consequently, survival and timing of emergence followed similar trends even though percent fines varied between the two.

1992

Survival-to-Hatching

Proximity to a tributary appeared not to affect STH significantly although data from 1991 suggested a relationship. Possibly, fines infiltration was not severe in 1992 due to lower tributary flows. However, elimination of this variable enabled a clearer analysis of the principal effects through increased sample size and increased degrees of freedom. Although STH was not significantly different between reaches, annual precipitation was less and baskets were removed prior to the largest storm of the year. In addition, survival was higher in the affected reach than in the two combined control reaches (Prairie Creek above Brown Creek and Lost Man Creek).

Only one basket below Brown Creek out of 40 experienced 100% mortality and this basket had the highest infestation of oligochaete worms. The adjacent basket within the same site with no worms had the highest STH. The other site with worms had similar results (i.e., low STH for the infested basket and higher STH for the non-infested basket). Although suppositions from such small amounts of information are limited, trends indicated worms had a detrimental effect on survival.

Natural Emergence Survival

Multiple peaks of fry emergence from natural redds were not detected in patterns of emergence as in 1991. This was because emergent traps were placed over redds just after spawning was completed, thus, traps did not encapsulate multiple redds. However, visual observations of redds indicated that large quantities of fines had accumulated on the surface of redds due to early placement of the traps. Emergence survival appeared somewhat lower than survival from artificial redds in both treatments. Quantities of fines accumulating upon natural redds were not determined.

Spawners entered the stream so sporadically that estimation of emergence from natural redds was not comparable to artificial redds. However, initiation and peak emergence timing on Lost Man Creek redds approximated the peak on Prairie Creek although water temperatures on Lost Man Creek were higher than those on Prairie Creek (Figure 15). Large numbers of young-of-the-year fry were not seen in Prairie or Lost Man Creeks by stream surveyors until approximately this time as well, indicating that un-trapped natural redds exhibited similar emergence timing.

Most significantly, 94% (88 of 94 total redds counted) of the spawning occurred below the Brown Creek confluence in 1992. Because natural emergence survival was lowest below

Brown Creek, production by natural spawners was probably seriously affected as in 1991.

Although results indicated that the percentage of fine sediment measured by weight (regardless of size class) infiltrating cleaned stream gravel was significantly higher in the control than in the affected treatment, differences were not large (less than 1% by weight and less than 3% by volume). Significant within-subject effects and interaction terms confounded interpretation of data, and measured differences were more likely due to variation between sites within treatments or chance variation. Although trends suggested mean percentages were also higher in the control by volume (Figure 18), differences were not significant. This strengthened the assumption that the difference in the percentage of fines infiltrating stream gravel over the incubation period between reaches were not appreciably different.

A fluctuating pattern of seepage over the incubation period was apparent in artificial redds. Patterns such as these have been identified in other studies (McDonald and Shepard 1955). In the affected area, permeability generally decreased in most redd egg pockets (Figure 20). A significant SITE effect was also detected indicating temporal variability between left and right sites. However, this difference was small, and probably due to chance variation. Differences in hydraulics at individual redd sites appeared the most meaningful factor.

In the control reach, (Figure 20), permeability measurements more strongly reflected natural variability, increasing in some redds and decreasing in others. Significant interaction terms negated any interpretation of the main effects for either test. Differences were small, and as stated above, can probably be attributed to variation in individual redd sites. In addition, inflow rate would be expected to decrease by these amounts measured, as fines re-infiltrate cleaned gravel under natural conditions.

There were no initial differences in inflow rate between treatments, which was a crucial assumption needed to be tested for detecting differences in final inflow rates between treatments. However, no significant differences were found between final inflow rates either. My analysis indicated that differences within sites were smaller than differences between sites, within treatments or between treatments.

Even though decreases in inflow rates were observed over the study period, only minute changes in DO rates were measured in artificial redds. Dissolved oxygen concentrations in any of the pipes never dropped below 10.3 ppm, and the range for most pipes was between 10 ppm. to 12.5 ppm. These levels were only slightly lower than adjacent surface water levels, and are well within the tolerance of incubating salmonid eggs (CDFG, 1980). Moreover, measured differences in concentrations can probably be attributed to either differences in temperature, i.e., saturation potential, or to variation in calibration of the instrument.

Plots demonstrated the relationship between increasing fines and decreasing inflow rate, indicating multi-collinearity. The fact that the relationship between STH and other variables decreased but the adjusted r^2 increased when the inflow variable was removed from the regression, further strengthened the assumption that fines and final inflow were related, although weakly.

For explaining STH, variability introduced through using multiple brood stock explained 38% of the variability in STH. Percent fines alone explained only 14% of the variability. Together, the two variables explained 54% of the variability in STH. This was consistent with data from other studies which show that sediment in stream gravel varies linearly and inversely with percentage of fine sediment in stream gravel and that 'fish effects' can be significant.

Other confounding variables unmeasured or ineffectively controlled (site geometric mean particle size, stream gradient and flow, and numbers and distribution of oligochaete worms) may be confounding any direct relationship between survival and the main effects tested.

CONCLUSIONS

Although my study succeeded in terms of hatching fry from fertilized eggs, and trapping emerging fry from artificial redds, measuring the physical effects of fine sediment on eggs and related physical factors (flow of water and dissolved oxygen) on incubation survival proved difficult. Due to the continuing drought, in both years spawners entered the stream sporadically instead of in distinct runs, and in both years I experienced difficulties obtaining ripe females for egg tests. This dictated basket placement, which varied over time during both years' storm periods, thus intrusion of fines into baskets also varied.

Since both artificial and natural survival test conditions varied between and within years, data from the two years could not be pooled to increase sample size for testing differences between the affected and control reaches. In addition, presence of predatory oligochaete worms were an unplanned added variable, and modified methods had to be adapted to quantify their effects.

The use of temperature degree days to predict incubation period length proved an effective estimator of hatching and emergence timing to within several days. In 1991, initial hatching and emergence in Prairie Creek were markedly delayed when compared to control baskets. In 1992, fry hatched out within several days of the control baskets. Natural emergent fry traps successfully in trapped fry, but accretion of fines on the surface of the redd, and superimposition by other spawners prior to trap placement compromised experimental control. Length of incubation and reproductive success of natural spawners could also not be compared with artificial redds, as date of redd initiation, and percent survival of fry from adult spawners could not determined.

Overall incubation survival in both study years was much lower than the literature indicates, and significant differences in hatching and emergence survival were detected between treatment reaches in 1991. No entrapped developed fry were found in basket gravel indicating mortality occurred prior to the hatching stage, however timing of emergent basket placement was shown to have affected and confounded analysis of decreased emergence survival and its related cause. The effects of fine sediment on hatching survival were inconclusive, and no significant differences existed between treatment reaches in either years. Differences between reaches were detected for emergence baskets in 1991, however timing of basket placement confounded analysis as discussed above.

Results in 1991 did indirectly tie decreased survival to decreased gravel permeability, and predatory worm infestation, however. Although significant relationships were not found between egg survival and inflow rate, rates significantly declined with time and differed between treatment reaches in both basket types. Increases in fine sediment have shown to decrease permeability in many other studies as referenced. In this study, decreased inflow rates most likely decreased survival by slowing down elimination of metabolic wastes which incited fungal infection (fungus was readily observed). Reduced DO supply was ruled out as an affected process as no differences existed between treatment reaches, or between artificial redds and adjacent surface water.

Although, significant relationships could not be found between number of predatory worms and egg survival, presence of worms in baskets generally decreased survival rates by 100 to 400%. When worms were present in high abundance and fines were greater than 25%, hatching survival was zero. When no worms were present and fines were less than 16% there was relatively good survival. In addition, worms were never found in large masses in any gravel samples taken in 1991 or 1992, only in egg baskets and natural redds.

In 1992, mean hatching survival was on the average three times higher than in 1991. In 1992, only 2.5% of baskets experienced 100% mortality, compared to 60% in 1992. In 1992, mean percent fines were, on the average, about half, and worms were less abundant in egg baskets (5%

infested versus 61%) and in stream gravel than in 1991. In short, in 1992, percentage of fine sediment was appreciably less, worm infestation was much reduced, and survival was appreciably higher than that in 1991. Since storm conditions in 1992 were generally less destructive than those experienced in 1991, intrusion of fines into stream gravels were less, thus effects on egg survival were generally less detrimental.

Improved sampling strategy in 1992 allowed better statistical analysis, and while the best data set and model indicated percent fines explained only 14% of the variability in survival, variability introduced through using multiple brood stock explained 38%. This was consistent with data from other studies which show that survival varies linearly and inversely with percentage of fine sediment in stream gravel and that 'fish effects' can be significant.

Other confounding variables unmeasured or ineffectively controlled (site geometric mean particle size, stream gradient and flow, and numbers and distribution of oligochaete worms) may be confounding any direct relationship between survival and the main effects tested.

Due to inconclusive results, but improved stream conditions documented by this study, in 1993, Caltrans discontinued egg survival studies, but continued mitigation efforts of planting artificially-spawned native juvenile salmonids into Prairie Creek.

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Appendix A. Summary of Data from Hatching and Emergent Baskets within Artificial Redds on Prairie Creek, CA 1991.

SITE	HATCHING SURVIVAL (%)	WORM ABUND. (rank)	FINES(%) < 1 mm WEIGHT	FINES(%) < 1 mm VOLUME	BEGIN INFLOW (cm^3/sec)	FINAL INFLOW (cm^3/sec)	INFLOW CHANGE (cm^3/sec)
HATCH BASKETS							
bb[1]1	0.00	1	5.63	13.87	132.97	85.29	-47.68
bb2	0.00	1	12.37	17.75	84.84	49.21	-35.63
bb3	0.00	3	0.89	5.31	75.60	33.72	-41.88
bb4	1.17	3	2.59	8.83	85.94	76.05	-9.89
bb5	0.00	3	3.36	16.04	73.28	74.27	0.98
bb6	0.00	0	4.53	11.74	111.86	84.35	-27.51
bb7	0.00	0	6.41	11.61	94.77	57.47	-37.30
bb8	3.04	0	1.52	4.93	87.07	54.02	-33.05
bb9	3.04	2	2.88	8.61	87.81	78.13	-9.67
bb10	0.00	1	3.74	14.92	63.97	64.48	0.52
ab[2]1	44.58	0	4.69	8.08	62.14	117.92	55.70
ab2	0.00	0	3.39	13.01	76.21	95.86	19.65
ab3	0.00	3	3.78	15.45	108.90	66.87	-42.04
ab4	2.33	0	2.28	9.50	78.51	65.11	-13.41
ab5	0.00	3	4.62	16.73	67.52	89.21	21.70
ab6	16.74	2	4.72	15.68	86.15	31.30	-54.85
ab7	0.00	3	4.70	21.69	61.11	79.40	18.29
ab8	19.78	0	1.29	3.88	90.87	82.31	-8.56
ab9	7.00	0	3.33	11.87	57.26	83.71	26.45
ab10	0.00	0	1.86	6.92	69.31	60.76	-8.55

SITE	EMERGENT SURVIVAL (%)	WORM WEIGHT (gm)	INES (% < 1 mm WEIGHT	INES (% < 1 mm VOLUME	BEGIN INFLOW (cm^2/sec)	FINAL INFLOW (cm^2/sec)	INFLOW CHANGE (cm^2/sec)
EMERGENT BASKETS							
bb1	0.00	0.69	10.16	15.20	82.42	6.18	-76.24
bb2	0.00	1.00	9.66	21.93	128.70	78.69	-50.01
bb3	0.00	2.00	9.17	21.31	99.08	60.53	-38.55
bb4	0.00	121.00	6.74	15.25	133.86	89.99	-43.87
bb5	32.42	3.90	1.36	9.73	140.07	75.12	-64.95
bb6	24.46	50.30	2.05	12.86	106.00	123.11	17.11
bb7	0.00	41.50	6.67	18.67	97.47	103.64	6.17
bb8	31.79	0.00	1.96	14.17	99.42	82.87	-16.55
bb9	28.52	0.00	4.34	17.44	115.30	114.25	-1.06
bb10	5.59	0.23	1.87	12.18	105.16	68.00	-37.17
ab1	12.17	0.00	6.18	24.22	95.12	100.47	5.35
ab2	45.38	0.00	2.12	13.36	61.26	95.68	34.43
ab3	10.65	55.50	2.56	15.26	64.27	80.95	16.69
ab4	1.52	0.23	2.16	14.27	47.01	82.95	35.93
ab5	4.57	76.00	2.53	19.35	89.74	70.25	-19.50
ab6	40.95	0.60	2.50	12.21	67.67	70.54	2.87
ab7	59.95	0.00	2.09	9.36	91.26	45.65	-45.61
ab8	34.66	0.92	1.65	10.34	55.98	108.37	52.38
ab9	1.52	0.00	2.00	6.94	67.72	82.12	14.40
ab10	1.52	0.00	0.00	0.00	77.40	71.62	-5.77

bb[1]# = below Brown Creek on Prairie Creek

ab[2]# = above Brown Creek on Prairie Creek

Appendix B. Summary of Fine Sediment Data Collected from Hatching and Emergent Baskets within Artificial Redds on Prairie Creek, CA, 1991.

SITE	FINES (%) < 4.75 mm WEIGHT	FINES (%) < 1 mm WEIGHT	FINES (%) < 0.5 mm WEIGHT	FINES (%) < 4.75 mm VOLUME	FINES (%) < 1 mm VOLUME	FINES (%) < 0.5 mm VOLUME
HATCH BASKETS						
bb[1]1	8.28	5.63	4.54	15.77	13.87	13.19
bb2	16.09	12.37	7.03	19.51	17.75	15.61
bb3	1.53	0.89	0.76	5.87	5.31	5.19
bb4	4.07	2.59	2.21	9.77	8.83	8.62
bb5	4.44	3.36	2.90	16.51	16.04	15.89
bb6	7.06	4.53	3.07	12.99	11.74	11.13
bb7	10.72	6.41	3.68	13.67	11.61	10.44
bb8	3.45	1.52	1.12	5.92	4.93	4.71
bb9	4.82	2.88	2.24	9.72	8.61	8.27
bb10	5.57	3.74	2.68	15.88	14.92	14.42
ab[2]1	8.04	4.69	2.24	10.47	8.08	6.39
ab2	4.76	3.39	2.55	14.07	13.01	12.69
ab3	6.01	3.78	2.92	16.51	15.45	15.07
ab4	3.09	2.28	1.83	10.09	9.50	9.22
ab5	5.80	4.62	3.38	17.33	16.73	16.20
ab6	5.97	4.72	3.43	16.53	15.68	14.94
ab7	6.92	4.70	2.95	23.13	21.69	20.90
ab8	2.80	1.29	0.82	5.51	3.88	3.50
ab9	4.76	3.33	2.82	12.75	11.87	11.62
ab10	3.45	1.86	1.09	8.28	6.92	6.33
EMERGENT BASKETS						
bb1	22.40	10.16	4.90	26.23	15.20	10.78
bb2	16.60	9.66	6.10	27.42	21.93	19.44
bb3	20.16	9.17	4.58	29.18	21.31	18.53
bb4	12.63	6.74	4.46	18.08	15.25	14.27
bb5	2.80	1.36	1.21	10.70	9.73	9.63
bb6	3.05	2.05	1.75	13.81	12.86	12.61
bb7	10.48	6.67	3.95	22.01	18.67	16.42
bb8	2.51	1.96	1.73	14.71	14.17	13.96
bb9	6.82	4.34	3.25	19.50	17.44	16.64
bb10	4.27	1.87	1.52	14.31	12.18	11.90
ab1	10.42	6.18	2.86	33.60	24.22	17.40
ab2	2.84	2.12	1.86	14.77	13.36	13.16
ab3	3.88	2.56	2.14	16.49	15.26	14.87
ab4	3.52	2.16	1.79	15.51	14.27	13.93
ab5	3.71	2.53	2.35	20.40	19.35	19.16
ab6	4.17	2.50	2.05	13.93	12.21	11.76
ab7	5.53	2.09	1.42	12.22	9.36	8.85
ab8	3.81	1.65	1.19	12.50	10.34	9.86
ab9	3.31	2.00	1.76	7.50	6.94	6.85
ab10	0.00	0.00	0.00	0.00	0.00	0.00

bb[1]# = below Brown Creek on Prairie Creek

ab[2]# = above Brown Creek on Prairie Creek

Appendix C. Summary of Dissolved Oxygen Concentrations (ppm) and Temperatures Measured within, and adjacent to, Artificial Redds in Prairie Creek, CA 1991.

SITE	HATCH CONC. (ppm)	EMERGENT CONC. (ppm)	STREAM CONC. (ppm)	STREAM TEMP. (°C)
BEGIN				
bb[1]1	11.6	11.2	11.2	7.1
bb2	11.0	11.1	11.1	7.1
bb3	10.7	11.2	11.0	7.0
bb4	11.6	11.6	11.5	6.0
bb5	11.8	11.6	11.8	7.0
bb6	11.8	11.6	11.7	6.6
bb7	11.9	11.9	12.0	6.5
bb8	11.3	11.7	11.6	6.5
bb9	12.1	11.9	12.1	6.5
bb10	10.8	11.0	11.1	6.8
ab[2]1	12.5	12.2	11.8	5.5
ab2	11.2	11.8	11.8	6.2
ab3	11.3	11.3	11.4	6.5
ab4	12.0	11.4	11.6	6.5
ab5	10.9	10.9	11.3	6.2
ab6	11.1	11.4	11.3	6.3
ab7	11.1	11.3	11.3	N/D[3]
ab8	11.0	11.7	11.3	6.0
ab9	11.1	11.2	11.2	6.5
ab10	11.1	11.5	11.3	6.0
FINAL				
bb1	10.5	11.2	11.8	8.4
bb2	10.8	11.8	11.9	8.6
bb3	11.7	N/D	11.8	8.0
bb4	11.9	11.7	11.8	8.4
bb5	11.0	10.7	11.7	8.2
bb6	11.1	10.9	11.3	9.2
bb7	11.5	11.5	11.6	9.3
bb8	10.4	11.8	11.8	7.9
bb9	10.7	10.9	11.1	9.0
bb10	10.2	10.3	11.6	7.9
ab1	N/D	11.2	11.7	8.2
ab2	10.4	10.6	11.3	9.0
ab3	11.3	11.0	11.9	9.1
ab4	9.6	10.3	11.3	7.5
ab5	10.9	11.3	11.9	7.9
ab6	10.3	10.9	11.2	8.5
ab7	10.2	10.1	10.8	7.5
ab8	10.7	11.9	12.0	8.0
ab9	9.4	11.2	11.6	8.0
ab10	N/D	N/D	N/D	8.0

bb[1]# = below Brown Creek on Prairie Creek
ab[2]# = above Brown Creek on Prairie Creek
N/D[3] = No Data

Appendix D. Site Averages for Data Collected from Hatching Baskets within Artificial Redds on Prairie Creek CA, 1992.

SITE	HATCHING SURVIVAL (#)	HATCHING SURVIVAL (%)	FISH ID. (#)	WORM WEIGHT (gm)	FINES (%) < 1 mm WEIGHT	FINES (%) < 1 mm VOLUME	BEGIN INFLOW (cm^3/sec)	FINAL INFLOW (cm^3/sec)	CHANGE IN INFLOW (cm^3/sec)
HATCH BASKETS									
bb[1]1	38.73	42.09	4	0	4.74	7.01	98.90	91.41	7.49
bb2	30.02	43.51	2	0	4.57	7.54	123.47	91.15	32.32
bb3	8.77	12.71	2	0	5.97	9.06	119.26	106.81	12.46
bb4	39.00	42.39	4	22	4.28	6.29	119.10	97.72	21.38
bb5	5.61	10.59	1	0	8.90	16.71	103.02	91.15	11.87
bb6	40.82	46.92	3	0	1.83	2.76	110.60	115.14	-4.54
bb7	27.36	51.63	1	0	3.99	7.33	95.87	92.92	2.95
bb8	39.67	43.12	4	0	1.99	3.02	95.28	92.67	2.61
bb9	44.44	51.09	3	0	17.19	20.45	93.76	100.75	-6.99
bb10	59.88	68.83	3	0	2.91	6.26	109.25	83.83	25.42
ab[2]1	26.43	49.87	1	0	1.46	2.59	124.57	101.25	23.31
ab2	6.83	12.88	1	0	0.98	1.60	98.81	90.65	8.16
ab3	53.32	57.95	4	0	5.65	7.30	122.38	96.46	25.92
ab4	26.50	28.80	4	0	8.71	12.04	103.10	76.26	26.85
ab5	16.21	30.59	1	0	3.24	5.25	89.55	96.96	-7.41
lm[3]1	14.55	27.45	1	0	20.00	34.47	122.72	95.45	27.27
lm2	7.28	10.55	2	0	8.83	12.70	121.37	99.23	22.14
lm3	40.14	48.25	3	0	10.49	15.27	117.83	94.44	23.40
lm4	22.89	24.88	4	0	10.34	14.85	108.91	78.28	30.64
lm5	20.92	30.32	2	11	7.33	19.35	101.00	79.79	21.21

bb[1]# = below Brown Creek on Prairie Creek
ab[2]# = above Brown Creek on Prairie Creek
lm[3]# = Lost Man Creek

Appendix E. Summary of Data Collected from Hatching Baskets within Artificial Redds on Prairie Creek, CA 1992.

SITE	HATCHING SURVIVAL (#)	HATCHING SURVIVAL (%)	FISH ID. (#)	WORM WEIGHT (gm)	FINES (%) < 1 mm WEIGHT	FINES (%) < 1 mm VOLUME	BEGIN INFLOW (cm^3/sec)	FINAL INFLOW (cm^3/sec)	CHANGE IN INFLOW (cm^3/sec)
HATCH BASKETS									
bb[1]l	45.45	49.41	4.0	0.0	0.24	2.51	106.22	99.49	6.73
bb1r	32.00	34.78	4.0	0.0	0.47	4.50	91.57	83.33	8.25
bb2l	41.49	60.13	2.0	0.0	0.31	3.28	123.39	92.42	30.97
bb2r	18.56	26.89	2.0	0.0	0.48	4.26	123.56	89.89	33.67
bb3l	13.54	19.63	2.0	0.0	0.34	3.43	129.11	113.12	15.99
bb3r	4.00	5.80	2.0	0.0	0.71	5.63	109.42	100.50	8.92
bb4l	78.00	84.78	4.0	99.0	0.62	2.63	115.14	107.57	7.57
bb4r	0.00	0.00	4.0	22.0	0.59	3.66	123.05	87.87	35.18
bb5l	1.02	1.93	1.0	0.0	1.96	9.77	107.57	88.38	19.19
bb5r	10.20	19.25	1.0	0.0	1.31	6.94	98.48	93.93	4.54
bb6l	50.00	57.47	3.0	0.0	0.21	1.14	106.39	112.11	-5.72
bb6r	31.63	36.36	3.0	0.0	0.23	1.62	114.80	118.17	-3.37
bb7l	26.32	49.65	1.0	0.0	0.46	3.80	108.74	95.95	12.79
bb7r	28.41	53.60	1.0	0.0	0.75	3.53	82.99	89.89	-6.90
bb8l	33.33	36.23	4.0	0.0	0.14	1.17	102.52	104.03	-1.51
bb8r	46.00	50.00	4.0	0.0	0.17	1.85	88.04	81.31	6.73
bb9l	29.29	33.67	3.0	0.0	0.48	3.74	84.67	115.14	-30.47
bb9r	59.60	68.50	3.0	0.0	1.14	16.71	102.85	86.36	16.50
bb10l	44.00	50.57	3.0	0.0	0.63	3.98	104.70	84.34	20.37
bb10r	75.76	87.08	3.0	0.0	0.34	2.28	113.79	83.33	30.47
ab[2]l	19.19	36.21	1.0	0.0	0.25	1.38	133.83	96.46	37.37
ab1r	33.67	63.53	1.0	0.0	0.23	1.21	115.31	106.05	9.26
ab2l	3.13	5.90	1.0	0.0	0.10	0.72	74.57	99.99	-25.42
ab2r	10.53	19.86	1.0	0.0	0.23	0.88	123.05	81.31	41.75
ab3l	63.64	69.17	4.0	0.0	0.30	1.95	108.74	97.47	11.28
ab3r	43.00	46.74	4.0	0.0	1.28	5.35	136.01	95.45	40.57
ab4l	32.00	34.78	4.0	0.0	0.86	4.19	91.41	88.38	3.04
ab4r	21.00	22.83	4.0	0.0	1.51	7.85	114.80	64.14	50.67
ab5l	10.20	19.25	1.0	0.0	0.23	2.24	87.53	97.47	-9.93
ab5r	22.22	41.93	1.0	0.0	0.67	3.01	91.57	96.46	-4.88
lm[3]l	19.00	35.85	1.0	0.0	3.93	18.40	131.81	89.89	41.92
lm1r	10.10	19.06	1.0	0.0	3.05	16.07	113.63	101.00	12.63
lm2l	9.30	13.48	2.0	0.0	1.12	4.99	108.91	100.50	8.42
lm2r	5.26	7.63	2.0	0.0	2.01	7.71	133.83	97.97	35.85
lm3l	54.77	59.54	3.0	0.0	0.68	5.46	119.52	107.06	12.46
lm3r	25.51	36.97	3.0	0.0	1.48	9.81	116.15	81.81	34.34
lm4l	32.65	35.49	4.0	0.0	1.76	6.27	98.48	90.90	7.57
lm4r	13.13	14.27	4.0	0.0	2.36	8.58	119.35	65.65	53.70
lm5l	10.53	15.26	2.0	11.0	2.42	14.44	93.93	84.34	9.60
lm5r	31.31	45.38	2.0	99.0	1.06	4.91	108.07	75.25	32.83

bb[1]#l = left basket below Brown Creek on Prairie Creek

ab[2]#r = right basket above Brown Creek on Prairie Creek

lm[3]#r = right basket on Lost Man Creek

Appendix F. Summary of Fine Sediment Data Collected from Hatching Baskets within Artificial Redds on Prairie Creek, CA 1992.

SITE	FINES (%) < 4.75 mm WEIGHT	FINES (%) < 1 mm WEIGHT	FINES (%) < 0.5 mm WEIGHT	FINES (%) < 4.75 mm VOLUME	FINES (%) < 1 mm VOLUME	FINES (%) < 0.5 mm VOLUME
HATCH BASKETS						
bb[1]1l	2.50	0.24	0.18	4.79	2.51	2.44
bb1r	1.84	0.47	0.38	5.96	4.50	4.41
bb2l	2.64	0.31	0.29	5.64	3.28	3.25
bb2r	4.54	0.48	0.45	8.11	4.26	4.23
bb3l	2.88	0.34	0.30	5.93	3.43	3.37
bb3r	3.49	0.71	0.62	8.33	5.63	5.55
bb4l	4.19	0.62	0.30	6.38	2.63	2.29
bb4r	3.12	0.59	0.31	6.16	3.66	3.39
bb5l	7.32	1.96	1.35	14.98	9.77	9.13
bb5r	4.64	1.31	0.97	10.16	6.94	6.58
bb6l	2.37	0.21	0.13	3.82	1.14	1.04
bb6r	2.43	0.23	0.17	3.91	1.62	1.55
bb7l	2.25	0.46	0.36	5.56	3.80	3.70
bb7r	2.97	0.75	0.35	5.82	3.53	3.09
bb8l	2.38	0.14	0.10	3.52	1.17	1.11
bb8r	1.92	0.17	0.14	3.97	1.85	1.79
bb9l	2.51	0.48	0.42	5.79	3.74	3.69
bb9r	2.07	1.14	1.12	17.52	16.71	16.70
bb10l	3.90	0.63	0.25	7.26	3.98	3.59
bb10r	1.67	0.34	0.23	3.68	2.28	2.18
ab[2]1l	1.49	0.25	0.17	2.73	1.38	1.27
ab1r	2.81	0.23	0.16	3.79	1.21	1.12
ab2l	2.16	0.10	0.09	3.01	0.72	0.70
ab2r	2.63	0.23	0.22	3.71	0.88	0.86
ab3l	2.03	0.30	0.21	3.75	1.95	1.86
ab3r	4.68	1.28	0.56	8.82	5.35	4.63
ab4l	5.75	0.86	0.54	9.12	4.19	3.87
ab4r	6.82	1.51	0.78	13.09	7.85	7.15
ab5l	1.84	0.23	0.20	3.91	2.24	2.21
ab5r	2.58	0.67	0.45	4.98	3.01	2.80
lm[3]1l	5.37	3.93	3.91	19.63	18.40	18.38
lm1r	7.42	3.05	2.15	19.76	16.07	15.15
lm2l	4.55	1.12	0.85	8.27	4.99	4.72
lm2r	4.13	2.01	1.22	9.70	7.71	6.97
lm3l	4.60	0.68	0.50	9.20	5.46	5.30
lm3r	6.04	1.48	1.24	14.03	9.81	9.59
lm4l	6.34	1.76	0.97	10.63	6.27	5.54
lm4r	11.73	2.36	1.41	17.41	8.58	7.67
lm5l	7.12	2.42	1.49	18.56	14.44	13.65
lm5r	3.95	1.06	0.65	7.69	4.91	4.54

bb[1]#l = left basket below Brown Creek on Prairie Creek
ab[2]#r = right basket above Brown Creek on Prairie Creek
lm[3]#r = right basket on Lost Man Creek

Appendix G. Summary of Dissolved Oxygen Concentrations (ppm) a Temperatures Measured within, and adjacent to, Artificial Redds in Prairie Creek, CA 1992.

SITE	LEFT BASKET CONC. (ppm)	RIGHT BASKET CONC. (ppm)	STREAM CONC. (ppm)	STREAM TEMP (°C)
BEGIN				
bb¹1	11.5	11.5	11.4	7.0
bb2	11.0	11.0	11.0	6.5
bb3	12.5	12.5	12.5	5.5
bb4	11.4	12.0	12.0	6.0
bb5	N/D	12.0	12.0	6.0
bb6	12.3	12.4	N/D	6.0
bb7	12.2	12.2	11.8	6.0
bb8	11.8	12.0	11.8	6.0
bb9	12.2	12.4	12.2	6.0
bb10	12.4	12.4	12.2	7.0
ab²1	12.3	12.8	12.9	6.0
ab2	12.1	12.3	12.4	6.0
ab3	11.6	11.4	11.6	8.0
ab4	13.5	13.6	13.6	6.0
ab5	11.6	11.5	11.5	8.0
lm³1	13.1	13.2	13.5	5.5
lm2	13.3	13.4	13.2	5.5
lm3	11.6	11.7	11.6	8.0
lm4	11.9	11.6	11.7	7.0
lm5	11.9	11.8	11.9	8.0
FINAL				
bb1	10.1	11.0	11.5	10.5
bb2	10.7	10.8	11.1	10.1
bb3	11.4	11.0	11.5	9.5
bb4	11.0	11.0	11.4	9.5
bb5	10.4	10.8	11.1	10.5
bb6	10.5	N/D	11.0	10.0
bb7	10.5	10.6	11.2	10.0
bb8	10.6	10.4	10.9	9.5
bb9	10.8	11.2	11.3	10.0
bb10	10.2	10.8	11.2	10.0
ab1	10.1	10.6	11.0	9.7
ab2	11.1	11.0	11.6	9.7
ab3	11.1	10.7	11.4	9.5
ab4	10.0	10.8	11.3	8.5
ab5	11.0	10.9	11.5	9.0
lm³1	10.5	11.2	11.8	9.0
lm2	10.0	10.5	11.4	10.0
lm3	10.0	10.5	11.9	9.0
lm4	10.9	10.1	11.4	9.0
lm5	10.5	10.6	11.2	9.2

bb¹# = below Brown Creek on Prairie Creek
ab²# = above Brown Creek on Prairie Creek
lm³# = Lost Man Creek
N/D = No Data